Inventory and Monitoring Program
Pacific Island Network

Monitoring Plan

Phase 2, Draft last updated: 30 September 2004

Parks

Ala Kahakai National Historic Trail (ALKA), Hawaii
American Memorial Park (AMME), Commonwealth of the Northern Mariana Islands
Haleakala National Park (HALE), Hawaii
Hawaii Volcanoes National Park (HAVO), Hawaii
Kalaupapa National Historical Park (KALA), Hawaii
Kaloko-Honokohau National Historical Park (KAHO), Hawaii
National Park of American Samoa (NPSA), Territory of American Samoa
Puuhonua o Honaunau National Historical Park (PUHO), Hawaii
Puukohola Heiau National Historic Site (PUHE), Hawaii
USS Arizona Memorial (USAR), Hawaii
War in the Pacific National Historical Park (WAPA), Territory of Guam

Authors

Fritz Klasner	Ecologist	Pacific Island Network
Sonia Stephens	Monitoring Plan Specialist	Pacific Cooperative Studies Unit

Editors

Raychelle Daniel	Workgroup Facilitator	Pacific Cooperative Studies Unit
Gordon Dicus	Data Manager	Pacific Island Network
Leslie HaySmith	Network Coordinator	Pacific Island Network
Darcy Hu	Ecologist	Pacific West Regional Office
Melia Lane-Kamahele	Cartographer	Pacific West Regional Office
Linda Pratt	Botanist	USGS—PIERC

Approval Signatures:

Eric Brunneman, Superintendent, War in the Pacific National Historical Park

Eric Brunneman, Superintendent, American Memorial Park

Doug Neighbor, Superintendent, National Park of American Samoa

Doug Lentz, Superintendent, USS Arizona Memorial

Tom Workman, Superintendent, Kalaupapa National Historical Park

Don Reeser, Superintendent, Haleakala National Park

Aric Arakaki, Superintendent, Ala Kahakai National Historic Trail

Daniel Kawaiaea, Superintendent, Puukohola National Historic Site

Geri Bell, Superintendent, Kaloko-Honokohau National Historical Park

Geri Bell, Superintendent, Puuhonua o Honaunau National Historical Park

Cynthia Orlando, Superintendent, Hawaii Volcanoes National Park

Bryan Harry, General Superintendent, Pacific Area Office

Leslie HaySmith, Inventory and Monitoring Network Coordinator, Pacific Island Network

Penny Latham, Inventory and Monitoring Coordinator, Pacific West Region

Steven Fancy, National Monitoring Coordinator, Washington Support Office

Roy Irwin, Biologist (Water Resources Division representative), Washington Support Office

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PREFACE

The National Park Service (NPS) Monitoring Program website[1] provides information on the history, institutional guidance, and current status of the NPS Inventory and Monitoring Program. NPS Monitoring Program guidance[2] outlines a network approach to monitoring, incorporating a 3-phase planning and design process that will extend over four years. Phase 1 (FY2003) defined goals, set preliminary objectives, summarized existing data and understanding (including evaluating and synthesizing existing data), and developed conceptual ecological models. The first three chapters in the Pacific Islands Network (PACN) monitoring plan, comprising the bulk of this Phase 2 report (FY2004), describe Vital Signs prioritization and selection and include an update of the Phase 1 report. A Phase 3 report (FY2005-FY2006) will encompass a complete monitoring plan, see http://www1.nature.nps.gov/im/units/pacn/monitoring/plan/ for future versions.

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EXECUTIVE SUMMARY

Will be prepared in 2005.

Currently, this document and other portions of our monitoring plans are in-progress. They should be considered **draft** and not cited.

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[1] http://science.nature.nps.gov/im/monitor/
[2] http://science.nature.nps.gov/im/monitor/approach.htm

CHAPTER 1. INTRODUCTION AND BACKGROUND

A. PARK STEWARDSHIP AND NATURAL RESOURCE MONITORING

Knowing the condition of natural resources in national parks is fundamental to the Park Service's ability to manage park resources "unimpaired for the enjoyment of future generations". National Park managers across the country are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources as a basis for making decisions, and for working with other agencies and the public for the benefit of park resources.

Natural resource monitoring offers site-specific information needed to understand and identify change in complex, variable, and imperfectly understood natural systems and to determine whether observed changes are within natural levels of variability or may be indicators of unwanted human influences. Thus, monitoring provides a basis for understanding and identifying meaningful change in natural systems. Monitoring data help to define the normal limits of natural variation in park resources and provide a basis for understanding observed changes; monitoring results may also be used to determine what constitutes impairment and to identify the need for change in management practices. Understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate threats to these systems (Roman and Barrett 1999).

As used by the NPS, Vital Signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Because of the need to maximize the use and relevance of monitoring results for making management decisions, Vital Signs selected by parks may include elements that were selected because they have important human values (e.g., harvested or charismatic species) or because of some known or hypothesized threat or stressor/response relationship with a particular park resource; therefore, Vital Signs may or may not be indicators of overall ecosystem condition. The broad-based, scientifically sound information obtained through natural resource monitoring will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources.

Monitoring is a central component of natural resource stewardship in the NPS, and in conjunction with natural resource inventories, management, and research, provides the information needed for effective, science-based managerial decision-making and resource protection (Figure 1.1). Natural resource inventories are extensive point-in-time efforts to determine the location or condition of a resource, including the presence, class, distribution, and status of plants, animals, and abiotic components such as water, soils, landforms, and climate. Monitoring differs from inventories by adding the dimension of time; the general purpose of monitoring is to detect changes or trends in a resource. Elzinga et al. (1998) defined monitoring as "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective". Detection of a change or trend may trigger a management action, or it may generate a new line of inquiry. **Research** is generally defined as the systematic collection of data that produces new knowledge or relationships and usually involves an experimental approach, in which a hypothesis concerning the probable cause of an observation is tested in situations with and without the specified cause. A research design is usually required to determine the cause of changes observed by monitoring. The development of monitoring protocols also involves a research component to determine the appropriate spatial and temporal scale for monitoring.

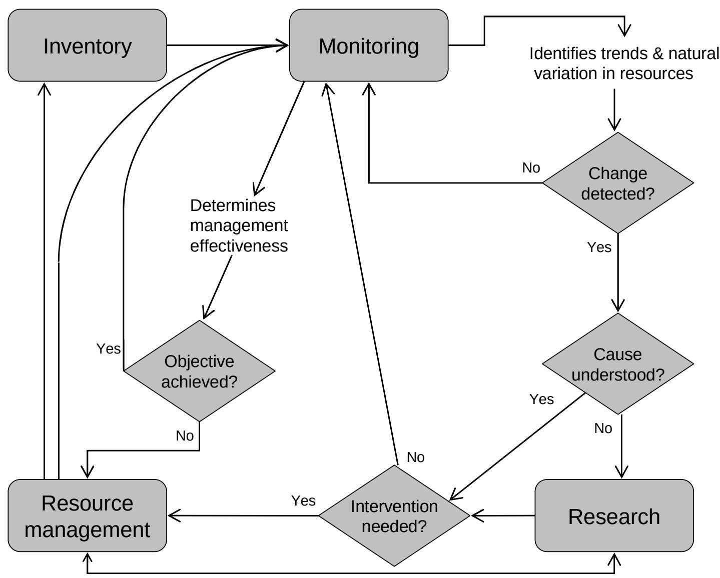

Figure 1.1. Stewardship of natural resources in national parks involves the interconnected activities of inventories, monitoring, research, and resource management (modified from Jenkins et al. 2002).

1. Goals of Vital Signs Monitoring

Thirty-two National Park Service Inventory and Monitoring Program networks have been established, of which the Pacific Island Network (PACN) is one. These networks are groups of parks linked by geography and shared natural resource characteristics. They were established to provide baseline resource information and long-term trends in the condition of National Park System resources, to facilitate collaboration and information sharing among parks in ecologically similar regions, and maximize economies of scale in natural resource monitoring and management.

The goal of NPS management policy is to use monitoring data "…to maintain- and where necessary, restore- the integrity of natural systems" (NPS 2001: 31). The PACN interprets servicewide goals for Vital Signs monitoring within the context of management policies pertaining to the restoration and maintenance of ecosystem integrity. Monitoring is an ongoing effort to better understand how to restore or sustain ecosystems, and serves as an "early warning system" to detect declines in ecosystem integrity and species viability before irreversible loss has occurred. In cases where natural systems in or surrounding the park have been so highly altered that natural processes no longer operate, managers must understand how the systems operate in order to determine the most effective approach for restoration. Monitoring program goals for the

PACN were adopted directly from the servicewide Inventory and Monitoring Program goals, with the addition of a sixth goal (in italics below) addressing shared natural and cultural values. The goals of Vital Signs monitoring are as follows:

- Determine status and trends in selected indicators of park ecosystem(s) condition to allow managers to make better-informed decisions and to work effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.
- *Provide data to better understand, protect, and manage important resources that share cultural and natural value.*

This sixth goal, related to resources that share cultural and natural value, will permit the network to more fully develop Vital Signs monitoring that address human activities and cultural practices. It will also help us develop a monitoring program that meets the legal considerations and other mandates that PACN parks must address.

An effective monitoring program provides information that can be used in multiple ways. The most widely identified application of monitoring information is that of enabling managers to make better-informed management decisions (White and Bratton 1980, Croze 1982, Jones 1986, Davis 1989, Quinn and van Riper 1990). Another use of monitoring information is to document changes primarily for the sake of familiarity with resources (Halvorson 1984, Croze 1982). By gathering data over long periods, correlations between different attributes become apparent, and resource managers gain a better general understanding of the ecosystem. A third use of monitoring information may be to convince others to make decisions benefiting national parks (Johnson and Bratton 1978, Croze 1982). Monitoring sensitive species, invasive species, culturally significant species, or entire communities can provide park managers, stakeholders, and the public with an early warning of the effects of human activities before they are noticed elsewhere (Davis 1989, Wiersma 1984). Finally, a monitoring program can provide basic background information that is needed by park researchers, public information offices, interpreters, and those wanting to know more about the area around them (Johnson and Bratton 1978).

2. Legislation, Policy, and Guidance for Natural Resource Monitoring

The enabling legislation establishing the National Park Service (NPS) and its individual park units clearly mandates, as the primary objective, the protection, preservation and conservation of park resources, in perpetuity for the use and enjoyment of future generations (NPS 1980). NPS policy and recent legislation (National Parks Omnibus Management Act of 1998) require that park managers know the condition of natural resources under their stewardship and monitor long-term trends in those resources in order to fulfill the NPS mission of conserving parks unimpaired (Figure 1.1). The laws and management policies that follow provide the mandate for inventorying and monitoring in national parks.

National park managers are directed by federal law and National Park Service policies and guidance to know the status and trends in the condition of natural resources under their stewardship in order to fulfill the NPS mission to conserve parks unimpaired (see Summary of Laws, Policies, and Guidance[1]). The mission of the National Park Service (National Park Service Organic Act, 1916) is:

"...to promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

Congress strengthened the National Park Service's protective function, and provided language important to recent decisions about resource impairment, when it amended the Organic Act in 1978 to state that "the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established…."

More recently, the National Parks Omnibus Management Act of 1998 established the framework for fully integrating natural resource monitoring and other science activities into the management processes of the national park system. The act charges the secretary of the interior to "continually improve the ability of the National Park Service to provide state-of-the-art management, protection, and interpretation of and research on the resources of the National Park System," and to "assure the full and proper utilization of the results of scientific studies for park management decisions." Section 5934 of the act requires the secretary of the interior to develop a program of "inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources."

Congress reinforced the message of the National Parks Omnibus Management Act of 1998 in its text of the FY 2000 Appropriations bill when it funded the Natural Resource Challenge:

"The Committee applauds the Service for recognizing that the preservation of the diverse natural elements and the great scenic beauty of America's national parks and other units should be as high a priority in the Service as providing visitor services. A major part of protecting those resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data."

The 2001 NPS Management Policies updated previous policy and specifically directed the service to inventory and monitor natural systems:

[1] *http://science.nature.nps.gov/im/monitor/LawsPolicy.htm*

"Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions."

Further, "The Service will:

- Identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge, to obtain information and data that will help park managers accomplish park management objectives provided for in law and planning documents.
- Define, assemble, and synthesize comprehensive baseline inventory data describing the natural resources under its stewardship, and identify the processes that influence those resources.
- Use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals.
- Analyze the resulting information to detect or predict changes, including interrelationships with visitor carrying capacities, that may require management intervention, and to provide reference points for comparison with other environments and time frames.
- Use the resulting information to maintain-and, where necessary, restore-the integrity of natural systems" (2001 NPS Management Policies).

Additional statutes that provide legal direction for expending funds to determine the condition of natural resources in parks and specifically guide the natural resource management of network parks are included in the following list (see also Summary of Laws, Policies, and Guidance[1]):

- *National Park Service Organic Act (1916):* establishes the purpose of national parks.
- *General Authorities Act of 1970:* unites individual parks into the 'National Park System'.
- *Redwood National Park Act (1988):* reasserts system-wide protection standards.
- *National Environmental Policy Act of 1969:* requires a systematic analysis of major federal actions.
- *Clean Water Act (1972):* designed to restore and maintain the integrity of the nation's water.
- *Clean Air Act (1990):* establishes a nationwide program for the prevention and control of air pollution and establishes National Ambient Air Quality Standards.
- *Endangered Species Act of 1973:* requires that federal departments and agencies shall seek to conserve endangered species and threatened species.
- *Coastal Zone Management Act of 1972:* establishes policy to preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone.
- *Marine Protection, Research, and Sanctuaries Act of 1972:* intended to improve the conservation, understanding, management, and wise and sustainable use of marine resources; (to) enhance public awareness, understanding, and appreciation of the marine environment; and (to) maintain for future generations the habitat, and ecological services, of the natural assemblage of living resources that inhabit these areas.
- *National Historic Preservation Act of 1966:* includes preserving 'the historical and cultural foundations of the Nation' and preserving irreplaceable examples important to our national heritage.

[1] *http://science.nature.nps.gov/im/monitor/LawsPolicy.htm*

- *Wilderness Act of 1964:* establishes the National Wilderness Preservation System (Wilderness Areas).
- *Geothermal Steam Act (1988):* specifically calls for a monitoring program for certain parks with thermal resources.
- *Hawaii Tropical Forest Recovery Act (1992):* authorizes biological control agents for non-native species, and creates a task force to develop an action plan to promote public awareness of the harm caused by introduced species and develop management recommendations for the protection of Hawaii's native biota from non-native species.
- *National Parks Omnibus Management Act (1998):* requires: increased efficiency, provides clear authority for the conduct of scientific study and use of information, appropriate documentation of resource conditions. Encourages: others to use parks for study, publication and dissemination of information derived from studies.
- *Executive Order 13112 on Invasive Species (1999):* intended to prevent the introduction of invasive species and provide for their control and to minimize impacts.

3. Strategic Planning and Performance Management

The Government Performance and Results Act (GPRA) of 1993 requires federal agencies to develop strategic plans as part of the performance management business system. The National Park Service uses the strategic plan and performance management system to set goals and then align activities, staffing, and funding to meet those goals. This monitoring plan specifically addresses GPRA Goal 1b3 "Identification of Vital Signs", but the scientific information collected, analyzed, and reported as part of this integrated monitoring program will also be used to address a number of other key goals related to natural resource stewardship. The GPRA goals relevant to monitoring in the PACN are listed in Table 1.1[1]. GPRA goals also exist for natural resource inventories, which support the monitoring program. Additionally, the development of partnerships for monitoring with other agencies and organizations will help parks meet other GPRA goals.

Table 1.1. Government Performance and Results Act Goals for the PACN.

Mission Goal	GPRA Goal	Goal #
Natural and cultural resources restored and maintained in good condition	Disturbed lands restored	Ia1A
	Exotic species contained	Ia1B
	Improved population status of federally listed Threatened and Endangered species	Ia2A
	Stable populations of federally listed Threatened and Endangered species	Ia2B
	Native species of concern at acceptable population levels	Ia2X
	Air quality stable or improving	Ia3
	Unimpaired water quality	Ia4
	Cultural landscapes in good condition	Ia7
	Paleontological resources in good condition	Ia9A
	Cave floors restored	Ia9B
Knowledge about natural resources	Vital Signs for natural resource monitoring identified	Ib3

[1] *Not all PACN parks have identified GRPR goals, so we are presenting a summary of goals for the network as a whole.*

B. Overview of the Pacific Island Network (PACN)

1. Geographical, Political, and Biogeographical Setting of the Network

The PACN covers an enormous sweep of the Earth across four time zones, spanning the northern and southern hemispheres, on either side of the International Date Line (Figure 1.2). With parks located throughout the tropical Pacific, the PACN is the most extensive network in the NPS Inventory and Monitoring Program. Spatially, the tropical Pacific Ocean is commonly divided into the three geographic areas of Polynesia (including Hawaii and American Samoa), Micronesia (including Guam and the Commonwealth of the Northern Mariana Islands [CNMI]), and Melanesia (see Loope 1998, Fig. 1[1]). Polynesia is the largest of these geographical areas, and based on other geologic and biotic differences the PACN can be further divided into three overarching regions: the Mariana Islands (Guam and the CNMI), American Samoa, and Hawaii. Resource management policies and practices throughout the network reflect local similarities and differences in island ecosystems and provide a link between the park units and the range of issues both internal and external to the parks. Shared characteristics of the PACN include:

- Many ecosystems and parks have relatively small sizes compared to many continental systems and national parks.
- Island ecosystems, prehistorically isolated from many outside influences, where the presence or absence of certain key taxa can result in important differences in ecosystem ecology from similar continental systems.
- Invertebrate taxa comprise a significant portion of endemic biodiversity (Eldredge & Evenhuis 2002).
- Globally recognized endemic ecosystems and biodiversity hotspots (see for example, Mittermeier et al. 1999).
- Five of the six unique (of 867 worldwide) PACN ecoregions are classified as 'critical or endangered' for global conservation status, with the remaining one as 'vulnerable' status (Olson et al. 2001).
- Native ecosystems that are all vulnerable to invasive species.
- Native ecosystems that require active, hands-on management if their unique native biodiversity is to survive.
- Parks are inadequately staffed to address demands of rapidly changing island ecosystems.
- Pacific Islands are recognized as discrete units with great potential for use as models in understanding environmental change, already rapidly occurring in these islands.
- Local community social structures that have retained a significant portion of traditional Polynesian and Micronesian heritage.

[1] http://biology.usgs.gov/s+t/SNT/noframe/pi179.htm

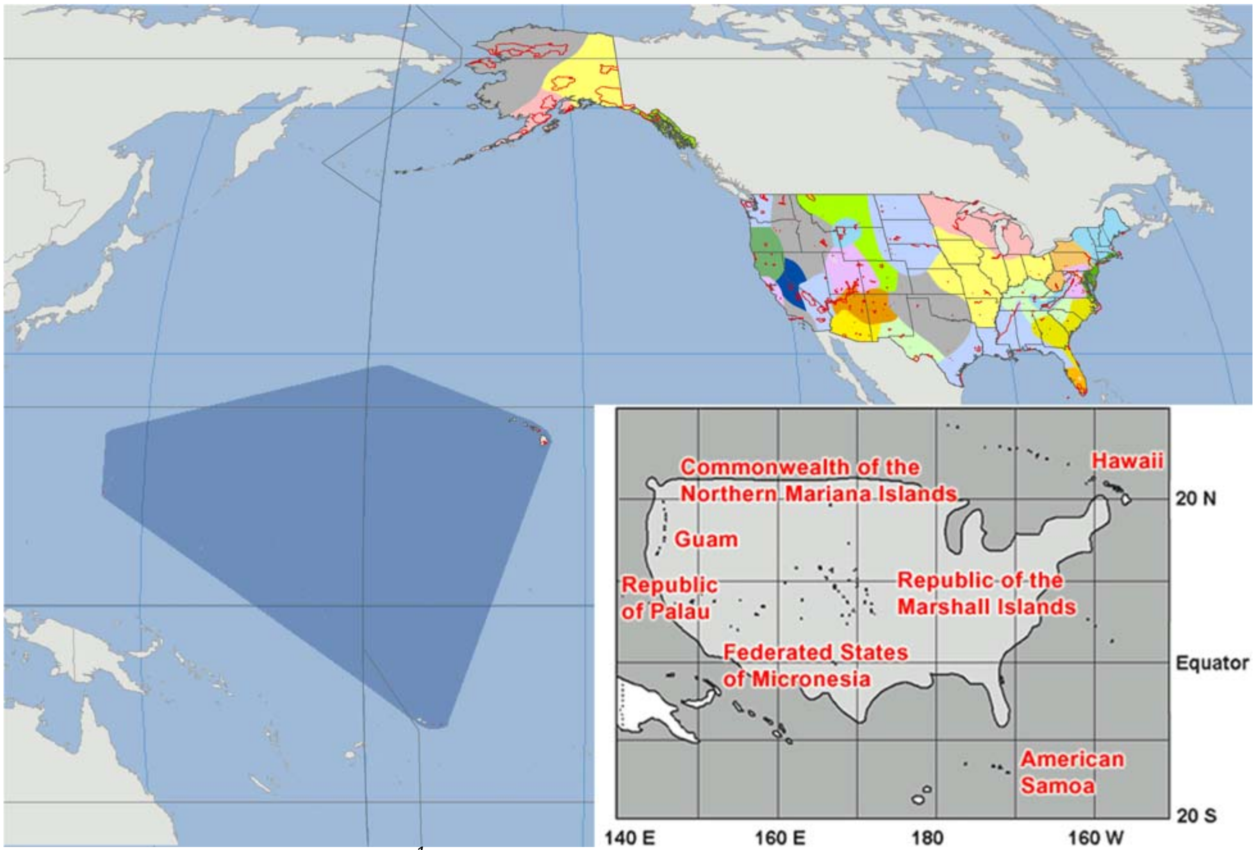

Figure 1.2. Pacific Island Network [1]

2. Parks of the PACN

The PACN includes 11 parks (Figure 1.3): War in the Pacific National Historical Park (WAPA) in the Territory of Guam, American Memorial Park (AMME) in the Commonwealth of the Northern Mariana Islands, National Park of American Samoa (NPSA) in the Territory of American Samoa, and in the State of Hawaii the USS Arizona Memorial (USAR) on the island of Oahu, Kalaupapa National Historical Park (KALA) on the island of Molokai, Haleakala National Park (HALE) on the island of Maui, and on the island of Hawaii: Ala Kahakai National Historic Trail (ALKA), Puukohola Heiau National Historic Site (PUHE), Kaloko-Honokohau National Historical Park (KAHO), Puuhonua O Honaunau National Historical Park (PUHO), and Hawaii Volcanoes National Park (HAVO).

[1] *Inset perspective to continental US courtesy of USGS Water Resources of Hawaii and the Pacific District Office, http://hi.water.usgs.gov/office/pacmap.html.*

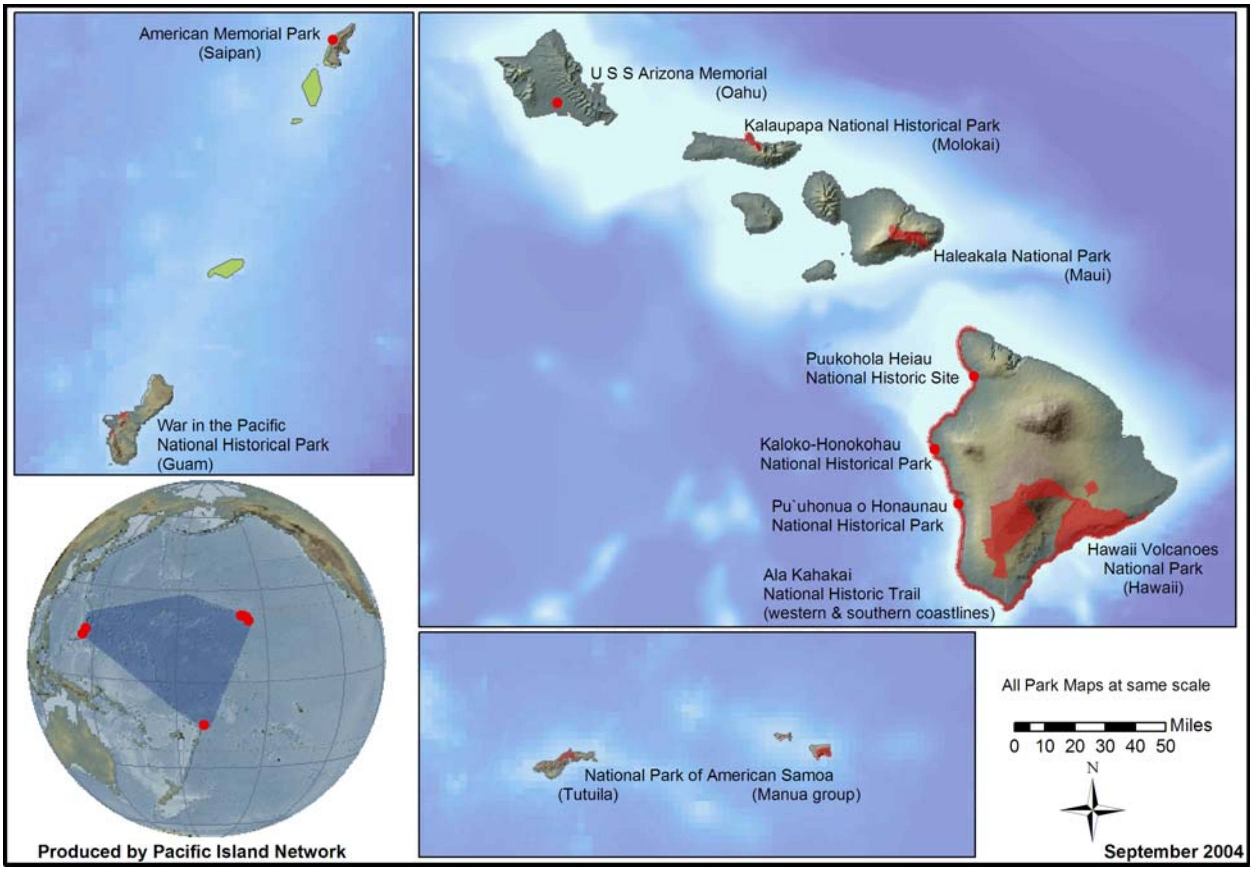

Figure 1.3. Maps of the 11 PACN Parks.

An overview of each park and its significant natural resources, management issues and priorities, existing monitoring, and other information can be viewed by navigating through the hyperlinked park names in Table 1.2 (or see http://www1.nature.nps.gov/im/units/pacn/monitoring/plan/2004/, park resource overviews). Below is a brief summary of each park's natural resources and management priorities.

War in the Pacific National Historical Park (WAPA): Designated as a historical park, terrestrial systems are to be managed in accord with conditions during the World War II time period (explicitly preserving features such as native plant communities and streams), while management of marine areas is intended to conserve the resources in a natural state. Natural resources include coral reefs, seagrass meadows, sandy beaches, estuaries, wetlands and streams, tropical savanna, limestone, and riverine forests, karst caves, and offshore islets. Primary threats to resources include tropical cyclones[1], high fishing pressure, marine debris and recreational damage, increasing urbanization, wildfires, invasive species, and chemical water and soil contamination.

American Memorial Park (AMME): Designated as a historical monument, management priorities include maintenance of recreational, environmental, and cultural resources. Natural resources include coral reefs (not under park jurisdiction), a sandy beach, a stream and estuary, and a wetland. Primary threats to resources include tropical cyclones, high fishing pressure,

[1] For simplicity, we use the term topical cyclone in this report for the entire PACN region to refer to storms with sustained wind speeds above 63 knots/hr even though the terminology varies by geographic region.

marine debris and recreational damage, increasing urbanization, invasive species, and chemical water and soil contamination. This park boundary ends at the high tide line.

National Park of American Samoa (NPSA): Designated as a national park, management priorities are to preserve rainforest and coral reefs while maintaining traditional land use; agriculture is permitted within the park. Natural resources include coral reefs, sandy and rocky beaches, estuaries, wetlands and streams, rainforests, and cloud forests. Primary threats to resources include tropical cyclones, high fishing pressure, marine debris and recreational damage, coral bleaching, expansion of agriculture, invasive species, and hunting.

USS Arizona Memorial (USAR): Designated as a national memorial, management efforts focus on the respectful maintenance of the memorial function. Natural resources primarily include the benthic community on the ship hull. Primary threats to resources include increasing urbanization, invasive species, and chemical water and soil contamination.

Kalaupapa National Historical Park (KALA): Designated as a historical park, of particular importance is maintaining the lifestyle of Hansen's disease patients as well as to maintain and preserve historic structures and traditional sites, values, and natural features. Natural resources include coral reefs, rocky and sandy beaches, offshore islets, estuaries, streams and a lake, rainforest, coastal and mesic forest, and caves and lava tubes. Primary threats to resources include water diversion and invasive species.

Haleakala National Park (HALE): Designated as a national park, management priorities focus on preserving natural resources. Natural resources include coastal strand, estuaries, streams, sub-alpine lakes and bogs, rainforest, mesic forest and cloud forest, sub-alpine grasslands and shrublands, alpine desert, and caves and lava tubes. Primary threats to resources include damage from recreational activity and invasive species. This park boundary ends at the high tide line.

Ala Kahakai National Historic Trail (ALKA): Designated as a historic trail, management priorities will include protection of both cultural and natural resources along the trail corridor; segments of the trail will be opened when the Comprehensive Management Plan is finalized (expected in early to mid 2005). Natural resources include sandy and rocky beaches, sea cliffs, fishponds, estuaries, anchialine pools and wetlands, and coastal strand, grassland, and forest. Primary threats to resources include sea level rise and subsidence, volcanic activity, high fishing pressure, marine debris, terrestrial and marine recreational damage, increasing urbanization and development, invasive species, water contamination, and groundwater withdrawal.

Puukohola Heiau National Historic Site (PUHE): Designated as a national historic site, management priorities focus on maintaining historic structures and a landscape similar to that in the time of Kamehameha I (late 1700s-early 1800s). Natural resources include coral reef, sandy beach, estuarine wetland, intermittent stream, and remnant dry forest. Primary threats to resources include high fishing pressure, marine debris and recreational damage, wildfires, invasive species, upland erosion and sedimentation of the wetland and bay, and water contamination.

Kaloko-Honokohau National Historical Park (KAHO): Designated as a historical park, management priorities include the maintenance of cultural activities and preservation of cultural and natural resources. Natural resources include coral reefs, sandy and rocky beaches, fishponds, wetlands and anchialine pools, grassland, lava fields, and coastal dryland forest. Primary threats to resources include sea level rise and subsidence, high fishing pressure, marine debris, terrestrial and marine recreational damage, increasing urbanization, invasive species, marine and groundwater contamination, and groundwater withdrawal.

Puuhonua o Honaunau National Historical Park (PUHO): Designated as a historical park, management priorities include maintaining the landscape as it looked in 1819. Natural resources include rocky shores, wetlands and anchialine pools, caves, and dryland forest. Primary stressors include sea level rise and subsidence, high fishing pressure, marine debris, recreational damage, invasive species, and marine and groundwater contamination. This park boundary ends at the high tide line.

Hawaii Volcanoes National Park (HAVO): Designated as a national park, management priorities focus on preserving natural resources. Natural resources include rocky and sandy beaches, sea cliffs, anchialine pools, lowland grassland, dry forest, rainforest, mesic forest, mid-elevation and alpine desert, lava fields, caves and lava tubes, sub-alpine shrubland, and multiple active volcanic features. Primary threats to resources include volcanic activity, damage from recreational activity, wildfires, and invasive species. This park boundary ends at the high tide line.

Table 1.2. Summary of land and water characteristics for each park in the PACN.

Park	Authorized (year)	Coastline length (mi)[a]	Authorized Marine size (ac)[b]	Authorized Terrestrial size (ac)[c]	Authorized Total Size (ac)[d]	Elevation Range (ft)[e]
WAPA	1978	5.8	1,006	1,031[h]	2,037[f]	-164–1,042
AMME	1976	3.2	0[h]	133[h]	133[f]	0–10
NPSA	1988	41.4[b]	4,679	9,355[b]	14,034[b]	-164–3,123
USAR[i]	1978	??	5.5	11	16.5[f]	-38–75
KALA	1980	16[h]	2,060	8,719	10,779[f]	-200–4,222
HALE	1916	1[h]	0[h]	28,969	28,969	0–10,023
ALKA	2000	To be determined	To be determined	To be determined	To be determined	To be determined
PUHE	1972	1[h]	7	79	86[f]	-49–170
KAHO	1978	2.77	596	625	1,161	-151–80
PUHO	1961	2[h]	0	181[g, h]	181	0–900
HAVO	1916	32.7	0	207,643[g]	207,643[g]	0–13,679

a Authorized coastline length figures are drawn from NRMap unless otherwise noted.
b Calculated using park boundary GIS data. Identified as 0 where authorized park boundary ends at high tide line. In marine areas within the State of Hawaii neither management nor ownership has been transferred to the NPS (as is also the case in several terrestrial areas throughout the network).
c Determined by subtracting authorized marine size from authorized total size.
d Authorized total size figures are drawn from NRMap unless otherwise noted, includes in-holdings and other areas authorized but where management has not been transferred.
e Determined using figures provided by the NPS Lands division (otherwise using USGS digital elevation models for land surfaces and bathymetry data (when available) for marine areas.
f From park web page.
g For HAVO: does not include 116,000 acre Kahuku addition, for PUHO: does not include Kiilae addition.
h Differs significantly from GIS calculations.
i USAR does not have formal congressional authorization, but operates under an interagency agreement with the US Navy.

3. Ecological Context

The vast geographical range of the PACN means that parks in different parts of the network possess different species and in some cases entirely different habitats. For example, native species in one area of the network may be highly invasive in another (e.g., mangroves), creating difficulties when attempting to develop specific network-wide management and monitoring objectives. However, ecosystems across the Pacific share many common features. The following section summarizes key natural resources or resource types and key stressors found throughout the PACN.

a. Key Natural Resources

PACN parks contain many of the freshwater, marine, and terrestrial ecosystems found on Pacific Islands. Because of the high level of endemicity and evolutionary isolation of Pacific Island flora and fauna, many species are now threatened or endangered. PACN parks support multiple species of concern. Several PACN parks also contain unfragmented habitats, a rare occurrence on small islands with high population densities and historic levels of human activity. Another key natural process is the volcanic activity associated with the parks.

Table 1.3. Summary of natural resources of PACN parks.

	AMME	WAPA	NPSA	USAR	KALA	HALE	ALKA[a]	PUHE	KAHO	PUHO	HAVO
Surface Water (Fresh & Brackish) Resources											
streams (perennial, intermittent, and ephemeral)	X	X	X	X[d]	X	X	X	X		X	X
wetlands, mangrove or swamp forest, bogs, seeps, or fishponds	X	X	X		X	X	X	X	X	X	X
lakes and ponds					X	X					
anchialine pools					X		X	X	X	X	X
Marine Resources[b]											
coral reefs	X	X	X	X	X	X	X	X	X	X	
seagrass meadows	X	X									
coastal and strand communities	X	X	X	X	X	X	X	X	X	X	X
Terrestrial Resources											
native-dominated wet forest (rainforest, cloud forest, mesic forest; not including swamp or mangrove forest)		X	X		X	X					X
native-dominated dry forest and grassland					X	X	X				X
alien-dominated wet forest		X	X		X	X	X				X
alien-dominated dry forest and grassland	X	X	X		X	X	X	X	X	X	X
alpine desert & subalpine scrubland						X					X
caves and lava tubes			X		X	X	X		X	X	X
lava fields and non-alpine desert						X	X		X		X
predator-free offshore islets		X	X		X						
active volcanic processes											X
Species of Concern (incl. threatened & endangered species)	X	X	X	X	X	X	X	X	X	X	X
Unfragmented Habitats		X[c]	X		X	X			X[c]		X

a Resources of ALKA have not been determined.
b In cases where park boundaries end at high-tide line, marine resources include those lying outside park boundaries.
c Marine habitats.
d Several streams drain into Pearl Harbor and one borders the park.

Surface water resources: Multiple types of surface water ecosystems are found within the PACN parks, including streams, wetlands, lakes, and anchialine pool systems. Freshwater species endemic to the PACN include waterbirds, fish, shrimp, snails, damselflies and other insects, sedges and other flowering plants, and ferns. Many of these groups include species or genera endemic to individual islands or groups of islands and having highly specific habitat requirements, for example, the endemic Hawaiian damselfly genus *Megalagrion*, with 22 species (Polhemus & Asquith 1996). Freshwater and anchialine biological habitats are a finite resource in the PACN and have often been modified or obliterated through land-use practices and invasive species introductions. A summary of water bodies within or adjacent to PACN parks and further details are available in the Freshwater Biology report in Appendix A.

- *Streams* in the PACN include perennial (flowing to the sea all year), intermittent (seasonally flowing), and interrupted (with lower reaches seasonally dry, but always having water in their upper reaches) systems. Perennial streams or stream portions provide habitat to completely aquatic species such as fish, while intermittent portions may be important as breeding habitat for insects and feeding areas for other fauna. Estuarine regions of Pacific Island streams are important biologically as both a breeding ground and nursery for marine fishes and as a link between freshwater and marine environments for migratory species.

- *Wetlands* found in the PACN include upland bogs and marshes, lowland marshes and swamps (including mangrove forests), springs, seeps, and man-made fishponds. Springs and seeps can be present at any elevation, and serve as important breeding grounds for endemic damselflies and snails. Mangrove forests are native to Saipan, Guam, and Samoa, but not the Hawaiian Islands. Fishponds are man-made coastal structures with brackish water, used in the past for farming of marine and estuarine fish species. Pacific Island tropical alpine bogs are rare, and coastal wetlands (particularly mangrove forests) are recognized as being threatened throughout the Pacific Islands.
- *Lakes* and ponds are found in HALE and KALA. Lakes are rare ecosystems on Pacific Islands; the HALE ponds are bog-associated upland systems and Lake Kauhako in KALA is a brackish pit crater lake unique within the United States. Rare species associated with these systems include insects and shrimp.
- *Anchialine pools* are surface expressions of complex, subterranean brackish water systems formed by the interaction of fresh and saline groundwater and lacking surface connections to the sea. They are rare worldwide, and within the United States are only present on the younger Hawaiian Islands. Several rare, threatened, or candidate endangered species are found in these systems.

Marine resources: All parks in the PACN contain or adjoin significant marine or coastal resources. Unique ecosystems found in the PACN include coral reefs, mangroves, seagrass beds, hard- and soft-bottom intertidal regions that support highly diverse species, and beaches that serve as important habitat for endangered sea turtles and monk seals. Marine ecosystems across the Pacific share many common features, specifically the ecological processes that shape them, such as dispersal, recruitment, growth, calcium carbonate accretion and erosion, and the stressors that alter them. Further details are available in the Marine report in Appendix A.

- *Coral reefs* are found in shallow tropical salt waters and are constructed primarily by hermatypic or reef-building corals- colonial marine invertebrates that photosynthesize via algal symbionts within their tissues and deposit extensive calcium carbonate skeletons that eventually form the foundational matrix of the ecosystem. Coral reefs are diverse and complex marine ecosystems, often drawing comparisons to tropical rainforests in terms of species numbers and complexity of interactions (Connell 1978, Birkeland 1997). Globally, coral reefs are at-risk and imperiled by many stressors, including both anthropogenic (e.g., sedimentation) and naturally occurring (e.g., heavy weather and increasing sea surface temperature) sources. Coral reef communities in the Indo-Pacific national parks (AMME & WAPA) have the greatest species diversity while endemism in the geographically isolated Hawaiian Islands for reef building corals is high (~20%). At Ta`u Island (NPSA), large coral bommies (*Porites* sp.) are among the largest living coral colonies in the world.
- *Seagrass communities* are found within the PACN only at WAPA and adjacent to AMME. They are comprised of marine flowering plants that occur in predominately shallow, soft-bottom coastal waters and estuaries (Kirkman 1990). They are important in stabilizing sediments reducing suspended material within the water column and improving coastal water quality, but are susceptible to smothering by heavy sedimentation. They often serve as nursery grounds for ecologically or economically important coral reef species and are critical to the long-term health of the coral reef ecosystem. Globally, they are an

ecosystem at risk and imperiled primarily from anthropogenic sources (e.g., sedimentation) and natural stressors (e.g., tropical cyclones).

- *Coastal and strand communities* are located on strips of coral sand or rock adjacent to the shoreline. They are unique ecosystems containing species adapted to salt spray, storm surge and shifting substrate that are often limited by nutrients and water. Endangered sea turtles use beaches for nesting and monk seals (*Monachus schauislandi*) frequently haul out on them to bask. These coastal strand communities have aesthetic value and help prevent erosion of beach areas. A unique feature found within the PACN are the black and green sand beaches (found at HAVO and ALKA),

Terrestrial resources: The Pacific Islands are globally recognized for their terrestrial biodiversity and conservation status by organizations such as the World Wildlife Fund (WWF) and Conservation International. Additionally, the Hawaiian Islands, and to a lesser extent other Pacific islands, are notable for some of the world's highest levels of endemism in many taxonomic groups as a result of biological evolution in isolation with very limited colonization from the outside (Loope 1998). Several well-known groups include birds, flowering plants, and insects. These Hawaiian species and many lesser-known examples (e.g., Howarth 1993, Gillespie et al. 1994) rival the famed Galapagos finches as textbook examples illustrating the process of evolution. Roughly 18,000 native species have evolved in place from about 2,000 colonizing ancestors in the Hawaiian Islands (Loope 1998). Specific details are available in the appropriate topical reports in Appendix A.

- *Native-dominated wet forest* includes both montane cloud forest and lowland rain forest, both recognized as globally rare ecosystems, as well as mesic forest. The rain forest is a climax forest but in Hawaii differs from most continental climax assemblages because the dominant species are largely the original colonizing species. Montane cloud forests have become refuges for plant and animal species whose lower elevation habitat has been lost. Cloud forests also control watershed water supply and quantity. On Pacific Islands, rain forests and cloud forests were more extensive before human colonization, but are now only remnants. The Samoan cloud forests are rich in epiphytic orchids and bryophytes, particularly on the older islands, and forest tree species are correlated with the age of the volcanic soil. Hawaiian and Samoan rain forests are less species-rich than in Melanesia. The National Park in Samoa preserves the only mixed-species paleotropic rainforest in the U.S.
- *Native-dominated dry forest and grassland.* The dry forest zone of the Hawaiian Islands lies between the coastal communities and higher elevation rainy areas. Typical vegetation includes the Hawaiian persimmon (lama, *Diospyros sandvicensis*), noi (*Eugenia* spp), soapberries (a'e and aula, *Sapindus* spp), and the native grass, pili (*Heteropogon contortus*). These communities are rare and threatened by urbanization and invasion of alien species. The Samoan islands do not have a dry leeward side, due to the high rainfall and lesser relief of the islands as compared to Hawaiian peaks.
- *Alien-dominated wet forest* and *alien-dominated dry forest and grassland*: While dominated by alien species, these ecosystems often contain remnant populations of threatened or endangered native plants and animals. Alien-dominated ecosystems are now more extensive than native-dominated in all of the Pacific Island Network parks. Alien species often deplete groundwater supply, pose greater fire risks, and/or change soil nutrient dynamics. Guam is covered by a mosaic of small vegetation patches of extremely

varied composition. There is very little undisturbed primary forest remaining on Guam; the forests are mostly second growth, many of them irregular thickets, generally dense, tangled, and often with spiny undergrowth. The southern half of Guam contains more grasslands, threatened by alien grasses.

- *Alpine desert and subalpine scrubland* ecosystems are rare in the tropics. Only HALE and HAVO contain these systems, due to the height of their volcanic peaks. The endemic silversword, `ahinahina (*Argyroxiphium* sp.), is found in this zone. The stature of flora is limited by the sparse precipitation. Frost occurs nightly almost year round but the solar radiation is also intense. Several threatened and endangered endemic arthropod and bird species are found within these ecosystems.
- *Caves and lava tubes* are unique ecosystems with highly specialized invertebrate fauna. These systems are easily disturbed and legally protected. Almost all parks in the Hawaiian chain contain these features. Lava tube ecosystems contain few noticeable plant species and are dominated by varied small animal forms. The primary energy supply is through roots from above ground vegetation, particularly ohi`a lehua (*M. polymorpha*). Older islands contain fewer lava tubes, as they tend to collapse. Caves and lava tubes frequently contain sensitive cultural sites. Traditional Hawaiian beliefs hold that cave burial sites containing human bones should not be disturbed. NPSA and WAPA potentially have cave and lava tube features but have not been surveyed.
- *Lava fields and non-alpine desert*: Lava fields are examples of successional ecosystems. A new lava flow may require many months to cool sufficiently to allow invasion of vegetation. In Hawaii, the general native vegetational sequence typically begins with colonization by blue-green algae. Mosses, ferns, and lichens then begin to establish, followed by ferns such as kupukupu (*Nephrolepis* spp.*)*, the then flowering plants. In Samoa, a mat-forming fern (*Dicranopteris linearis*) comes in on volcanic soils, associated with a club moss. The Samoan forests are not as subject to frequent large-area forest disturbances as the Hawaiian Islands. Non-alpine deserts support a range of dryland vegetation and animal species, including several rare insects and plants.
- *Predator-free offshore islets*: Worldwide, the biota of most islands have been impacted by introduced rats (*Rattus* sp.), and feral cats (*Felix sylvestris*). A small number of islets offshore of the main Pacific islands provide predator-free refugia for native plants and animals. Predator impact can be gauged by comparing native biodiversity on these islets with that in adjacent, predator infested areas.
- *Active volcanic processes*: All PACN parks are located on islands partially or completely formed by volcanic activity. Volcanic activity is of concern to most parks. However, only HAVO contains currently active volcanoes. Kilauea and Mauna Loa are two of the most active volcanoes in the world, and the Hawaii Volcano Observatory on Hawaii Island is a major research center dedicated to monitoring and analysis of volcanic processes.

Species of concern: The Pacific Islands contain a high proportion of the federally recognized threatened and endangered species in the Unites States. Isolation and the presence of unique microhabitats have fostered the evolution of many diverse species now threatened by habitat loss and alien species. A total of 174 federally listed threatened and endangered species are found in the PACN, this total includes all species whose known or predicted range covers one or more islands on which a PACN park exists (Table 1.4). Astoundingly, almost 17% of the federally listed endangered species can be found on these islands, if threatened or endangered species from the remaining islands within the PACN geographic region were included this list would total 332

(32% of the listed endangered species). A complete listing of federally listed threatened and endangered species that are found in the PACN can be found in Appendix D[1], including information on their geographical ranges, common and locally used names, and scientific names. There are also hundreds of species in multiple taxa, particularly plants, invertebrates and birds, which are scored by the Nature Conservancy and other agencies as "species of concern" or are candidates for listing as endangered.

Table 1.4. Numbers of federally listed threatened and endangered species found in the USA with the numbers found in the PACN separated by region (Hawaii and West Pacific).

	Endangered	Threatened	T & E Combined
USA[a]			
Total Animals	390	129	519
Total Plants	599	147	746
Flowering Plants	571	144	715
Ferns and Allies	24	2	26
Other Plants	4	1	5
USA TOTAL SPECIES	**989**	**276**	**1265**
PACN			
Total Animals	35	4	39
Hawaiian Islands	25	4	
West and South Pacific[b]	10	0	
Total Plants	131	4	135
Hawaiian Islands			
Flowering Plants	123	4	127
Ferns and Allies	7	0	7
Other Plants	0	0	0
West and South Pacific			
Flowering Plants	1	0	1
Ferns and Allies	0	0	0
Other Plants	0	0	0
PACN TOTAL SPECIES	**166**	**8**	**174**

a. USA numbers include Alaska, Hawaii, American Samoa, Guam, Northern Mariana Islands, Puerto Rico, and the US Virgin Islands.
b. West and South Pacific animal numbers exclude 5 species (sea turtles and humpback whales [3 endangered, 2 threatened]) because they are included in the Hawaiian Island animal numbers.

Unfragmented habitats: Most Pacific Island ecosystems have experienced significant past changes due to human activity. The few ecosystems in PACN parks that have not been fragmented due to land use and invasive species are recognized as significant resources. Unfragmented habitats vary by park, and include marine, terrestrial, and freshwater resources. The larger parks, such as HAVO, and the less developed units of NPSA, contain the best examples of unfragmented habitat.

[1] *This list includes all threatened and endangered species whose known or predicted range covers one or more islands on which a PACN park exists, and is based upon the lists maintained at the US Fish & Wildlife Service Threatened and Endangered species website (http://ecos.fws.gov/tess_public) for American Samoa, Guam, Saipan, Maui, Molokai, and Hawaii Island. Species lists will be updated after the NPSpecies database is certified.*

b. Key Stressors

Ecosystem stressors operating in PACN parks on Pacific Islands may be grouped into several categories. These include invasion and establishment by alien species, land and water use both within and outside parks, fire, natural hazards, and effects of global climate change. These stressors currently affect multiple parks within the network and are key management concerns.

Table 1.5. Summary of major, immediate stressors and natural resource management concerns of PACN parks.

	AMME	WAPA	NPSA	USAR	KALA	HALE	ALKA[a]	PUHE	KAHO	PUHO	HAVO
Invasive Species	X	X	X	X	X	X	X	X	X	X	X
Adjacent Land & Resource Use											
land use	X	X	X	X	X	X	X	X	X	X	X
water withdrawal and/or diversion	X	X	X	X	X	X	X	X	X	X	
erosion	X	X	X		X	X	X	X			
water quality (freshwater & marine)	X	X	X	X	X	X	X	X	X	X	
marine use[b]	X	X		X	X		X	X	X	X	
air quality	X	X		X		X	X		X	X	X
Fire		X			X	X	X	X	X	X	X
In-Park Use											
visitor damage	X	X				X	X	X	X	X	X
fishing	X	X	X		X		X		X	X	X
subsistence agriculture			X			X					
hunting & gathering (not including fishing)	X	X	X		X	X	X		X		X
Natural Hazards											
volcanic activity	X	X				X	X	X	X	X	X
frequent tropical cyclones	X	X									
Sea Temperature Increase			X								

a Resources of ALKA have not been determined.
b In cases where park boundaries end at high-tide line, marine resources include those lying outside park boundaries.

Invasive species: One of the major concerns of resource managers in the Pacific Islands is the invasion of alien species and displacement of native species. Invasive species have the ability to significantly affect ecosystem integrity (Harwell et al. 1999). Changes resulting from introduction of invasive species extend beyond alteration of ecosystem composition and affect ecosystem structure and function as well (e.g., Cuddihy and Stone 1990, Vitousek et al. 1996, Brasher 2003). In several Pacific Island ecosystems, alien species now form the dominant biological components, and restoration of native systems will require a large effort; in cases of extinction (e.g., of lowland birds and tree snails; see Burney et al. 2001) complete system restoration will not be possible.

Adjacent land and resource use is of concern to all PACN parks, though resources in some parks are threatened by adjacent use more than others. Several small PACN parks are located in or near developed areas which are experiencing rapid population growth. Adjacent land and water use are a concern for the large natural area parks, as well.

- *Land use* near parks affects natural resources. Several PACN parks are adjacent to or being affected by rapid urban, industrial, or resort development. Such land use changes contribute to ecosystem fragmentation, introduction of new invasive species, degradation of air and water quality, and light and sound pollution.

- *Water withdrawal and diversion* affects aquatic resources by lowering the water table and changing wetland and stream hydrology and habitat characteristics. Fresh water supply on Pacific Islands is limited, and population growth and development are placing increasing pressure on these resources. In PACN parks, stream diversion generally is associated with agriculture, whereas groundwater withdrawal is associated with irrigation, drinking, and other uses.
- *Erosion* is caused by land clearing, fires, storms, and activity of feral and domestic pigs, cattle, and goats. It affects water quality and habitat characteristics of terrestrial, freshwater, and marine resources. Erosion is a significant stressor in several parks.
- *Water quality* in the PACN is affected by multiple stressors, including input of herbicides, pesticides, and fertilizers, petrochemical spills, changes in hydrology, increased water temperatures and solar radiation, and erosion (discussed separately above). See Section c, below, for a longer overview of park water quality issues and water quality designations.
- *Marine use:* Use of marine resources outside park boundaries affects park natural resources in multiple ways. These include the potential introduction of invasive species to parks, water pollution and litter, overfishing or over-gathering of species, and changes in hydrology caused by harbor improvements.
- *Air quality* management policies in the PACN region reflect the isolated geography of the islands, in that locally generated pollutants are typically left to blow out to sea. Volcanic emissions are probably the single largest air quality concern, particularly on the island of Hawaii. See Section d, below, for park air quality designations and current monitoring; see also the Air Quality and Climate report in Appendix A for further detail.

Fire: Before human colonization, fire was very rare on most Pacific Islands, as lightning is uncommon; fires were associated with volcanic activity, however. Pacific Island species and ecosystems evolving under these conditions are extremely sensitive to fire. Many Pacific Island ecosystems have been extensively modified or destroyed through the use of fire since the time of first colonization. Fire destroys vegetation, facilitates invasion by alien species, and contributes to erosion.

In-park use: National Parks in the Pacific continue to experience an increase in visitation due to spectacular scenic vistas, wilderness areas, historical resources (both natural and cultural), and numerous other features. Providing the public with a venue to experience natural and cultural resources, while preserving resources "*unimpaired for enjoyment of future generations",* is the primary mission the park service is tasked with. PACN parks are used by the public in a variety of ways, some of which significantly impact natural resources.

- *Visitor damage*: Some direct physical impacts to natural resources from visitors include: trampling of native vegetation and coral reefs as foot traffic increases, soil and cinder compaction along trails, use of motorized vehicles, litter and waste supporting rodent populations, removal of objects, trespassing onto sacred places, and obstructing wildlife movement and foraging.
- *Fishing:* Most of the parks in the PACN, with the exception of HALE, include a coastal zone where fishing occurs. Fishing and the collection of shellfish, mainly opihi (*Cellana* spp.), has increased in the parks and threatens remaining communities. For example, ethnographic studies conducted at HAVO have found the amount of marine resources along the coast of the Kalapana Extension has decreased. The park's attempt to regulate

such activities has helped to reduce and maintain the stock, but there are still residents who come in and take opihi that are too small (Langlas 2003).

- *Subsistence agriculture:* Subsistence agriculture is not uncommon in PACN parks, as the park service allows traditional land use practices. For example, Kipahulu `Ohana is a group responsible for the revival and cultivation of 14 taro (*Colocasia esculenta*) patches within the Kipahulu Valley at HALE. NPSA is another park where subsistence farming is occurring, as there has been resurgence in the use of fallow areas within the park on the island of Tutuila. Monitoring in these areas is essential for early detection of degraded ecosystems, where farming practices facilitate erosion.
- *Terrestrial hunting and gathering:* Hunting has impacted the populations of several terrestrial species. One example is the Pacific pigeon (*Ducula pacifica*), Samoa's royal bird, which is responsible for transporting large seeds of the natural rainforest trees. A ban on hunting is in effect to preserve the remaining populations. While the gathering of plants is permitted in parks for traditional cultural or religious purposes, these activities can greatly reduce the amount of resources and create regeneration problems caused by invasive understory species.

Natural hazards: Pacific Islands can experience a variety of natural hazards due to their geographic setting and geologically active setting, and include volcanic activity, earthquakes, landslides, tsunami, and tropical cyclones. Natural hazard risks to parks vary by region and park geography. While Pacific Island ecosystems have evolved in concert with such natural events, large-scale disturbances may facilitate the invasion of alien species, and they are considered a threat to at-risk ecosystems. The Geology and Air Quality/Climate reports in Appendix A contain further detail on natural hazards.

- *Volcanic activity* is a hazard in several PACN parks to varying degrees. On Hawaii Island, Kilauea (affecting ALKA and HAVO), Mauna Loa (affecting ALKA, PUHE, PUHO, and HAVO) and Hualalai (affecting ALKA and KAHO) have erupted in the past 200 years and are therefore considered active, while on the island of Maui, Haleakala last erupted 400-500 years ago and is considered dormant. Kilauea and Mauna Loa are two of the most active volcanoes in the world. In the Marianas Islands, active volcanism is concentrated on the islands north of Saipan, and there is the possibility of ash fall on Saipan (AMME) and Guam (WAPA). See the Geology report in Appendix A for further detail.
- *Tropical cyclones* have affected all the islands in the PACN within the past 25 years; however, they are more frequent in the Western Pacific (Guam and Saipan). The destructive forces of tropical cyclones include storm surge, winds, salt stress, and heavy rainfall/flooding. The forces of the initial tropical cyclone and the loss of protection from further storms also lead to long-term problems with erosion and sedimentation with further damage to the shoreline and reefs. See the Air Quality and Climate report in Appendix A for further detail.

Sea temperature increase: Rises in average sea temperature are a cause of coral bleaching events, which are a severe threat to coral reef ecosystems (Brown 1996). Recent bleaching events in NPSA have been linked to increased water temperatures of only a few degrees. Sea temperatures are predicted to increase as part of global climate change, so this stressor is likely to affect other coral reef parks in the PACN.

c. ***Water Quality Designations and Monitoring***

Three types of water resources are shared by PACN parks; marine, freshwater, and groundwater. Network-wide concerns for these resources include atmospheric deposition, changes in hydrology and climate, chemical and microbial contamination, organic enrichment, invasive species, erosion, and sedimentation. Natural disturbance events contribute to the transfer of sediment and chemicals from land into nearby streams, groundwater and marine resources. Urban expansion often affects the hydrology of nearby ecosystems by diversion of streams and withdrawal of groundwater. Freshwater, wetland and estuarine habitats are important biologically and are especially vulnerable due to their small size and low flow. Human population growth alters the aquatic habitat physically when construction and recreation activities contribute to erosion, pollution, and the introduction of alien species. Chemicals from land-based sources enter groundwater via surface water connections, contaminating drinking water supplies and eventually coastal resources. In the circumstance of global climate change, solar radiation and ambient temperature affect water quantity and quality, and as a direct result, the well-being of organisms living in impacted areas.

PACN Water Quality Workgroup Planning Meeting

In the interest of collaboration, the water quality workgroup sponsored a planning meeting to consider the water quality monitoring plan and its purpose. Discussion topics focused on PACN water resource issues and values, water resource monitoring objectives, desired future conditions, water quality monitoring areas of interest, and potential partners. Ideas generated from this process are being used to develop the full monitoring plan. A complete report of this meeting is available at http://www1.nature.nps.gov/im/units/pacn/monitoring/plan/2003-pre/waterq/index.htm.

Potential Partners

In addition to working with others in our agency, it is critical to work with other organizations that also have water quality goals and objectives. Partnering with State, Territorial, and Local governing agencies is already occurring in the PACN due to the fact that submerged lands and their resources are often not owned or administered by the NPS. Approximately one third of the marine areas within War in the Pacific NHP in Guam are owned by the NPS. The remaining lands are owned by the Territory of Guam or the U.S. Navy. In American Samoa (AS), the offshore waters for the National Park of American Samoan are under government jurisdiction but administered by the local villages and the AS Department of Marine and Wildlife Resources manages and protects the marine resources. The Commonwealth of the Northern Mariana Islands (CNMI) owns and administers the submerged land adjacent to American Memorial Park (AMME). The State of Hawaii owns and administers the submerged lands below the high tide line within three miles of all fast land in the state through the Department of Land and Natural Resources. An extensive list of these and other potential partners is available in Appendix A: Water Quality Report.

Impaired and Outstanding Natural Resource Waters (ONRW)

Federal, State, and Territorial regulations on water quality standards provide a framework for designating and protecting water bodies for specific uses. Decisions made for this monitoring program are based on the current report of standards for each area (Hawaii-2004, American Samoa-1999, Guam-2003, and CNMI-2002). Designated uses for PACN water resources are listed for each park in Appendix A: Water Quality Report. The identification of impaired waters for 303(d) listing is limited by the shortage and small scope of existing monitoring programs and, although these programs are often state-based, territories and other affiliated nation-states have begun to participate in the process of identifying resources that are not meeting their designated uses. Table 1.6 lists the PACN water resources that have been identified as impaired by their State or Territory on the 2004 USEPA CWA 303(d) report.

Table 1.6. Park (or adjacent) waters on State or Territory 303d lists.

Park	303d Waters	Pollutants
WAPA	Agana Bay (adjacent) Northern Guam Lens Aquifer (adjacent)	turbidity and dissolved oxygen chlorides, nutrients, bacteria, and toxic contaminants
AMME	Saipan Lagoon (adjacent) N. Puerto Rico Dump (adjacent) S. Puerto Rico Dump (adjacent) Smiling Cove Marina American Memorial Park Outer Cove Marina (adjacent) Micro Beach Hyatt Hotel	Enterococci, dissolved oxygen, and orthophosphate Enterococci, dissolved oxygen, and orthophosphate Enterococci, dissolved oxygen, and orthophosphate Enterococci, dissolved oxygen, and orthophosphate Enterococci, dissolved oxygen, and orthophosphate Enterococci and orthophosphate Enterococci, dissolved oxygen, and orthophosphate Enterococci, dissolved oxygen, and orthophosphate
NPSA	None	n/a
USAR	Pearl Harbor Halawa Stream (adjacent)	nutrients, suspended solids, and PCBs nutrients and turbidity
KALA	None	n/a
HALE	None	n/a
ALKA	Pelekane Bay/Kawaihae Harbor Pelekane Bay/Spencer Park Beach Hapuna Beach Kailua Bay Magic Sands Beach Kealakekua Bay	turbidity turbidity and chlorophyll a turbidity total phosphorous turbidity and chlorophyll a turbidity
PUHE	Pelekane Bay/Kawaihae Harbor (adjacent) Pelekane Bay/ Spencer Park Beach (adjacent)	turbidity turbidity and chlorophyll a
KAHO	None	n/a
PUHO	None	n/a
HAVO	None	n/a

Several parks have unique and/or pristine water resources that could be considered as Outstanding National Resource Waters (ONRW) but this classification has not been developed by governments in the region. This provides an opportunity for the NPS I&M Program, together with other organizations, to set the precedent for evaluation and determination of such resources in Hawaii and the Pacific Territories. Table 1.7 lists PACN water resources that have been identified as candidates for ONRW status.

Table 1.7. Park waters identified as unique or pristine park resources.

Park	Resource	Details[a]
WAPA	Wetlands	Unique and rare in the region
AMME	Wetlands	Unique and rare in the region
NPSA	Coastal waters off Ofu and Ta`u Streams	Pristine Pristine in all units
USAR	None	n/a
KALA	Kauhako crater lake Streams coastal waters	Unique Pristine Pristine
HALE	Streams and springs coastal waters high elevation lakes and bogs	Pristine in Kipahulu district Pristine in Kipahulu district, adjacent to park Unique and pristine
ALKA	coastal waters wetlands	Pristine in many areas, adjacent to park Unique in the area and pristine

	streams anchialine pool complexes	Unique in the area Unique and pristine in many areas
PUHE	None	n/a
KAHO	Wetlands anchialine pools coastal waters	Unique Unique and mostly pristine Pristine
PUHO	Anchialine pools coastal waters	Unique Pristine, adjacent to park
HAVO	Anchialine pools coastal waters Ola`a bogs	Unique Pristine, adjacent to park Unique

a Outstanding Natural Resource Waters (ONRW) have not been designated in the PACN region.

Available Data and Hints of Trends

Trends in water quality for the region are not well developed due to the overall lack of available information. In regards to the CWA Section 305(b), regulatory reporting to the USEPA by the territories and the state of Hawaii demonstrates an increase in the number of impaired water bodies as determined by local water quality standards for their respective designated uses. This statement of an increasing number of impairments is misleading, as more water bodies are being monitored than before and previously unmonitored and unlisted resources are being added to the CWA Section 303(d) list.

Groundwater Monitoring

In spite of the widespread monitoring of groundwater by municipal drinking water suppliers and the USGS, there is very little information available on groundwater quality from collection wells inside PACN parks. Data available from the monitoring of Asan Spring, in WAPA, between 1996 and 1999 indicates low levels of synthetic organic chemicals and chromium. Adjacent to WAPA, the Northern Guam Lens Aquifer, as it is defined, may not extend beneath park boundaries, but is likely within the proposed water quality monitoring areas of interest for the PACN (See Appendix A: Water Quality Report). Although the boundaries of this aquifer lie upslope and to the North of the Asan unit of WAPA, it undoubtedly has an impact on nearshore areas of the park. This sole source aquifer is currently exceeding designated use criteria for chlorides, bacteria, nutrients, and toxic contaminants. A two-year study of spring water discharge from the Northern Guam Aquifer into the marine preserve of Tumon Bay, which lies to the North of WAPA, has recently been completed (PCR Environmental, 2002a; PCR Environmental, 2002b; and PCR Environmental, 2002c). Total discharge estimated for the springs is 17 million gallons per day. Chemicals detected above Guam EPA (GEPA) water quality standards in the discharges included PCE, TCE, aluminum, antimony, arsenic, magnesium, sulfate, oil and grease, total coliform bacteria and fecal coliform bacteria. Pesticides Dieldrin, alpha-chlordane, and gamma-chlordane were also detected in discharges. Impacts from the chemicals on Tumon Bay are planned to be mitigated by locating and eliminating sources of the chemicals.

Other groundwater data associated with PACN parks has been collected by the USGS and is limited to water level, conductivity, and chlorides for the determination of pumping capacity and utility as a drinking water or irrigation source. There is one such example in KALA where an exploratory well was evaluated in this way and determined to be insufficient for its intended use (HDLD 1963). Garrison et. al. (1999) suggest that all water bodies in the Hawaiian Islands should be considered coastal in nature due to the high porosity of the volcanic bedrock allowing for a high degree of connectivity between water resource types.

Surface Water Monitoring

The GEPA formerly monitored streams and rivers in the Surface Water Monitoring Network between 1980 and 1999 including three sites upslope of Agat along the Namo River and two from its mouth, and two sites in the Salinas River mouth. Turbidity and suspended solids were indicated as problem areas for these resources primarily during flood events. These rivers may currently be impaired, but the lack of monitoring data keeps them from being included on the 303(d) list. GEPA plans to reestablish monitoring of its rivers and streams in the near future. The AMME wetlands were surveyed for baseline salinity values by NPS, the Army Corps of Engineers (ACOE), and CNMI Fish and Wildlife Service in 1990 (Wagner) in preparation for the proposed Garapan Flood Control Project.

Between April to July, 1997, samples were collected from Laufuti Stream, Ta'u Unit, National Park of American Samoa from nine sites once and three stations three times. This data shows a wide variation in the dissolved oxygen and pH measurements along the length of the stream (Cook 2004). Another stream inside the Tutuila Unit of NPSA, Fagatuitui Stream, was monitored for one year as part of the EMAP by the American Samoa EPA (ASEPA). Results indicate that this stream is unimpacted compared to those in the same study that are located in more urbanized areas around Tutuila (DiDonato 2004).

Data available for KALA streams are measurements of flow by the USGS near diversion tunnels of headwater streams in the 1970s and early 1980s. Exceedances were noted for pH only in these data sets. Stream flow data has been collected intermittently at HALE by the USGS in areas concerned with diversion and withdrawal of water resources. DOH monitoring of Oheo Gulch provides a sparse, but long-term, dataset for this water body showing no significant changes or impairments in that resource

Numerous short-term water quality studies have been conducted in KAHO anchialine pools, fishponds and wetland areas (e.g., Maciolek and Brock 1974, Chai 1991, Brock and Kam 1997, Foote 2004). This information is still very disparate and will take a coordinated effort by NPS staff and researchers to compile the available information into a meaningful dataset.

Marine Water Monitoring

The GEPA Notice to the Public: 303(d) List for 2003-2004 noted sedimentation from land sources and nutrients discharged in groundwater as the primary causes of reef impairment on Guam. Limited data from the GEPA’s ongoing Recreational Beach Monitoring Program indicates the possibility of increasing turbidity and total phosphorous at Agat Bay reef flat, north of Agat Sewage Treatment Plant outfall from the late 1980s to the late 1990s. This outfall is out of use as of 2002 (Minton 2003). Agana Bay, to the East and up current of the Asan Unit, is also listed as impaired due to exceedances in turbidity and dissolved oxygen in more than ten percent of annual samples. The semi-enclosed embayment south of the Orote Peninsula and north of the Agat marine boundary has been the subject of fish consumption advisories due to contamination from PCBs and heavy metals from naval operations on the peninsula.

Denton and colleagues (1997) found evidence of contamination from chromium and nickel at Agat Marina and high levels of copper, lead and zinc in Agana Boat Basin to the East of the Asan Unit. Heavy metal contamination of these areas is attributed to the harbor operations and boat maintenance activities because higher levels are present where these activities are most prevalent and long-standing (GEPA 2000).

The CNMI DEQ has been monitoring five sites within AMME since 1994 for compliance with water quality standards for their designated uses as public swimming areas. Saipan Lagoon, offshore of AMME, and six coastal shoreline sites within or adjacent to park boundaries have demonstrated exceedances for Enterococci, dissolved oxygen, and orthophosphate. Only one of these sampling sites, Outer Cove Marina, was fully supportive of its designated uses, but for dissolved oxygen only. The report speculates that the water quality standards for orthophosphate are set too low because all water bodies tested around Saipan, Tinian, and Rota exceeded the set value. The Puerto Rico Industrial area, to the northeast and up-current of AMME, contains several more coastal sites within Saipan Lagoon that are also listed as impaired.

NPSA currently has long-term temperature loggers on the reef in Vatia and Ofu. Water temperature data, collected hourly by monitors within or near the park's reefs, has not been analyzed for trend at this point. ASEPA Ocean Water Monitoring: 3rd 1998 & 1st 2001 quarters. One site inside NPSA at Vatia Bay was established on the 2001 collection date. The data comes from water quality surveys conducted by the American Samoa Environmental Protection Agency in August 1998 and February 2001. The surveys were conducted in order to: (1) Determine current status of water quality surrounding the islands of Tutuila and Manu'a, (2) Obtain data to establish long term water quality trends, (3) Detect problem water bodies, (4) Verify appropriateness of American Samoa Water Quality Standards.

There is only one water quality project with data available for the immediate vicinity of the sunken USAR memorial. Results are forthcoming from an 18 month study that has recently (2004) been completed by the NPS Submerged Resources Center and USGS. Various other water quality assessments have taken place throughout Pearl Harbor, including sediment assessments by the US Navy and the Hawaii DOH (1978), indicating contamination of Pearl Harbor sediments by herbicides, pesticides, heavy metals, and PCBs and Leeward Community College environmental educational program led by Donald Klim (1997). Pearl Harbor is also the location of site-intensive studies in association with the EPA EMAP which is in its second round of random site selection for coastal assessment in Hawaii. Pearl Harbor has been shown to exceed water quality standards for nutrients, suspended solids, and PCBs. Pearl Harbor waters are delineated as the enclosed portion of the bay and nearshore waters to 30 feet from Keehi Lagoon to Oneula Beach. Several highly impacted streams that empty into Pearl Harbor have also been listed as impaired for nitrate/nitrite total nitrogen, turbidity, and trash.

In Hawaii, beach monitoring stations adjacent to PACN parks have been listed as impaired for turbidity, chlorophyll *a*, and total phosphorous. Honokohau Harbor, which lies inside KAHO but is not administrated by the park, has been assessed for water quality, circulation, and faunal changes which have deteriorated between the initial study in 1971 and the follow-up study after expansion of the harbor in 1979 (Bienfang 1980).

d. Air Quality Designations and Monitoring

Mandates for monitoring air quality in national parks depend on the classification of the area according to the Clean Air Act (CAA). Hawaii Volcanoes and Haleakala National Parks have been designated 'Class I' air quality areas. In these areas monitoring for visibility, pollutant gases, and particulate matter is mandatory. Maximum allowable increases in concentrations over baseline values are strictly regulated. All other PACN parks have been designated 'Class II' areas[1]. These areas are also protected under the CAA, but requirements for monitoring are not as strict as for Class I areas. There are no legal mandates for monitoring climate in the national parks. However, the 2001 NPS Management Policies state that "parks containing significant natural resources will gather and maintain baseline climatological data for perpetual reference." For more information on air quality and climate, see the Air Quality and Climate report in Appendix A. Table 1.8 summarizes current air quality and climate monitoring efforts in or near PACN parks.

Table 1.8. Air quality and climate monitoring efforts in or near PACN parks.

National Park or Site	Parameters Monitored	Time Period	Network or Program
Tutuila, American Samoa (15 km from NPSA)	Aerosols, gases, radiation, climate parameters	1970's - present	NOAA CMDL
Tutuila, American Samoa (various sites)	Climate parameters	1999 - present	USGS-WRD
Saipan, CNMI (various sites)	Rainfall	1994 - present	USGS-WRD
Guam (various sites)	Temperature, Rainfall	? - present	USGS-WRD
Pearl City, Oahu, Hawaii (2 km from USAR)	PM 2.5	1971 - present	Hawaii Department of Health, Clean Air Branch
KALA (Makapulapai)	Climate parameters	1993 - present	RAWS NFDRS
Olinda, Maui, Hawaii (6 km from HALE)	Visibility (aerosols)	1991 - present	IMPROVE
HALE (12 sites)	Climate parameters	1998 - present	HaleNet
HALE (Kaupo Gap)	Climate parameters	1991 – present	RAWS NFDRS
PUHO	Rainfall	1970 - present	NWS COOP
PUHO	Aerosols	2003 - 2004	VOGNET
PUHE	Temperature, Rainfall	1976 - present	NWS COOP
KAHO	Rainfall	? - present	NPS
HAVO	Aerosols – dry deposition, ozone	1999 - 2004	CASTNET
HAVO (several stations)	Climate parameters,	1999 - 2004	PRIMENet
HAVO	UV radiation	1999 - 2004	UVnet/PRIMENet
HAVO	Visibility (aerosols)	1986 - present	IMPROVE
HAVO	SO2	1986 - present	NPS Gaseous Pollutant Network
HAVO	Cloud presence and chemistry	1997 - 2003	University of Hawaii, Huebert
Mauna Loa Observatory, Hawaii, Hawaii (2 km from HAVO)	Aerosols, gases, radiation, climate parameters	1970's - present	NOAA CMDL

4. Desired Future Conditions

The "unimpairment" criterion of the NPS Organic Act emphasizes the process of identifying desired future conditions, monitoring the progress of management actions towards maintaining those conditions, and evaluating the effectiveness of management efforts in preventing further impairment. In addition, "…the goals for park planning and the desired future conditions for a park should focus on why the park was established and what resource conditions and visitor experiences should be achieved and maintained over time." (Directors Order #2, Park Planning).

[1] *NPS Natural Resource Reference Manual #77: http://www.nature.nps.gov/rm77/.*

Explicitly identifying desired future conditions as part of the monitoring program will help smooth the transition from Vital Sign selection to the establishment of specific, measurable objectives and trigger points for management.

Most Pacific island ecosystems are no longer representative of native species assemblages and in many cases are irrevocably altered (e.g., Burney et al. 2001), yet natural processes should be facilitated to the extent possible. In addition, ghost communities that are the result of resource partitioning and character displacement, sliding baselines (i.e., with each subsequent generation the “natural” baseline moves further from the true natural state), and management practices all must be taken into consideration when identifying ecologically relevant desired future conditions.

Desired future ecological conditions in Pacific Island National Parks, as identified at the PACN conceptual modeling workshop held in March 2003, include the following:

- Endemic, rare, and endangered biota and ecosystems will be protected.
- Degraded areas will be allowed to recover or will be restored, particularly environments conducive to the survival and perpetuation of native biological communities.
- Natural ecosystem processes (functions) continue to operate. “Natural” processes may also include those associated with native cultural practices where these are appropriate to a park’s mandate.
- Unnatural elements are removed from the system. This includes alien species control, eradication of highly disruptive species, and prevention of new alien species establishment.
- Re-establishment of extirpated or depleted species (composition), lost ecosystem processes (functions), and missing ecosystems structure(s) where feasible.
- Complete watersheds encompass a desired range of scales for management. Monitoring within watersheds may include the following elements:
    a. Composition: species ranges, diversity, and demographics;
    b. Structure: spatial arrangements of habitat and populations across multiple scales;
    c. Function: watershed metrics, such as the effects of land use practices on sediment and nutrient dynamics.

In addition, several other desired future conditions have been identified for the network monitoring program as a whole. These include adaptive management approaches that provide the flexibility to evaluate and change techniques as data are processed. The Inventory and Monitoring program monitoring design will be such that data will be defensible and database design, documentation, and archiving will be sound. The network monitoring program will:

- Expand our knowledge base and make available more knowledge than is currently accessible to both NPS staff and outside agencies.
- Promote scientifically defensible management criteria.
- Provide monitoring data which will document recovery (or lack thereof) in conjunction with management actions, and will facilitate funding of further management actions.
- Use an integrated, responsive approach of adaptive monitoring and management.
- Encourage and incorporate community involvement in planning and carrying out resource management activities and monitoring. The program will also incorporate living cultural practices (Hawaiian, Samoan, and Chamorro) where they do not impair natural resources.

- Educate the public through park-based interpretive programs beyond park boundaries and traditional park practices.
- Fulfill monitoring needs consistent with the NPS mission, resource protection goals, and enabling legislation for individual parks.

5. Legal and Management Issues Affecting Parks

A summary of documents that provide legal direction for determining the condition of natural resources in parks and specifically guide natural resource management in the network parks can be found online[1]. These documents include park enabling legislation, laws, policy, and resource management guidance. One issue that specifically affects PACN parks is the proper use of diacritical marks in spelling Hawaiian, Samoan, and Chamorro words in federal documents (for more information, see Appendix F: Geographic Names). Four significant legal and management concerns relevant to monitoring in the PACN are highlighted below.

a. Park Enabling Legislation Mandate for Monitoring

Enabling legislation of an individual park, where it exists, provides insight into the natural and cultural resources and resource values for which it was created to preserve. These values may evolve with time, through evolution of park management and legal interpretations to explicit additions to park enabling legislation.

For example, Hawaii National Park (now Hawaii Volcanoes [HAVO] and Haleakala [HALE] National Parks) enabling legislation provides for "preservation from injury of all timber, birds, mineral deposits, and natural curiosities or wonders within said park, and their retention in their natural conditions as nearly as possible". The mission of the US Geological Survey's Hawaii Volcano Observatory (HVO) includes monitoring volcanic and related hazards while increasing general understanding of these systems. HVO is identified in HAVO's enabling legislation documentation. Also in Hawaii, the enabling legislation for Kaloko-Honokohau NHP (KAHO) and its advisory committee directed the park to enter into air and water quality agreements with surrounding landowners utilizing the traditional ahupua`a (watershed) concept of land management. In another example, the enabling legislation for the National Park of American Samoa (NPSA) directs the park to "…preserve and protect the tropical forest and archaeological and cultural resources of American Samoa, and of associated reefs, to maintain the habitat of flying foxes, [and] preserve the ecological balance of the Samoan tropical forest…"

Many PACN parks commemorate conditions from World War II or local Polynesian culture in the late 1700s. Such a mandate in effect freezes ecological conditions and includes culturally introduced species, communities, and landscape characteristics. The cultural components of many PACN parks also include mandates to provide park materials in multiple languages, for example, English, Samoan, Chamorro, Hawaiian, or Japanese; in some cases many local residents speak little or no English, but rather one of the many indigenous Pacific rim languages. Several parks are also mandated to employ local residents to develop maintain and administer the park.

[1] *http://www1.nature.nps.gov/im/units/pacn/pacn_policy.htm*

b. State, Territorial, and Commonwealth Jurisdictions

Several parks contain leased lands and provide for differing management (and thus monitoring) considerations based on local arrangements. For example, NPSA leases all park lands in a 50-year renewable lease (with either party able to renege under certain conditions). Kalaupapa NHP (KALA) leases lands from the Department of Hawaiian Homelands, and works closely with the Hawaii Department of Health in managing park resources. American Memorial Park (AMME) on Saipan is an affiliated area that is controlled by CNMI (NPS presence is through lease agreements with CNMI via the US Navy). Several other parks have lease or other arrangements for use of or access to lands within authorized park boundaries. Such agreements also provide a foundation for partnerships and leveraging of resources for the joint administration, management and long-term stewardship, inventory and monitoring of resources.

c. Submerged Resources

Unlike emergent, dry, or fast (above mean high water level) lands, submerged lands and their resources are often not owned, leased, or administered by the NPS. In nearly every park, the NPS does not own or have administrative control over the submerged lands within its boundaries, and in most cases it is currently unclear what agreements, Memorandum of Understanding (MOU), or protocols are needed for the NPS to accomplish marine monitoring and conservation management goals. This inconsistency creates unique problems when implementing or enforcing management decisions or conducting monitoring. Approximately one-third of the submerged lands within War in the Pacific NHP (WAPA) are owned by the NPS; the remaining lands are owned by the Territory of Guam, which has ceded administrative control of these lands to WAPA through a MOU with NPS. Submerged lands within NPSA are owned by the Territory of American Samoa but are administered by the local villages. The State of Hawaii owns and administers the submerged lands below the high tide line within three miles of all fast land within the state. The USS Arizona Memorial (USAR) is operated by the NPS through an interagency agreement with the U.S. Navy.

d. Cultural Resource Concerns

Natural resource monitoring, as in other resource management programs, will include work that may directly or indirectly affect protected cultural resources, or involve the collection of natural resource specimens. Cultural resources can be found on land and underwater throughout the network. In most PACN parks, a connection exists between local, known individuals and families and these resources. Monitoring will respect that specific geographic or physical entities are not only held in trust for the people of the United States, but may be familial artifacts, history, or components of a community's culture. Cultural sensitivity appropriate to these stewardship concerns must also be reflected in collections, samples, or other activities required for monitoring. The thorough documentation of collection, identification, taxonomy, condition, and storage facility information is paramount in working with these collections; as is maintenance of both legally and culturally appropriate storage conditions conducive to long-term preservation.

C. Administration of the Pacific Island Network

The PACN is guided by a Board of Directors, composed of Superintendents from each of the parks plus the General Superintendent for the Pacific West Regional Office in Honolulu. The

Board specifies desired outcomes, evaluates performance for the monitoring program, and promotes accountability. The Network Coordinator and the Regional Inventory and Monitoring Program Coordinator serve as non-voting members on the board. The Board of Directors makes decisions regarding the development and implementation of the monitoring strategy, decisions on hiring, budgeting, and scheduling, and is responsible for ensuring the overall effectiveness and success of the network's monitoring efforts. The Board has established a Network Charter[1] to describe the organization and administration of the network.

The Network Charter established a standing Technical Committee to provide technical assistance and advice to the Board. The Technical Committee is comprised of natural resource managers and scientists, including scientists from outside the NPS, who work in the parks and are familiar with park issues. This Technical Committee, along with the Board of Directors, assisted the network in refining the scope of work for this monitoring plan.

Network staff (to be identified in detail in Chapter Eight) includes a Network Coordinator, Data Manager, and Ecologist. The Pacific West Regional Office Ecologist also provides guidance and assistance, including participation in Board of Directors activities. Several support positions for data gathering, synthesis, and management have been contracted through the Pacific Cooperative Studies Unit (PCSU). These positions include topical workgroup facilitators and park-based monitoring database specialists.

The Technical Committee established working groups in 10 topic areas: data management, air quality and climate, geology, vertebrate fauna, invertebrate fauna, freshwater biology, landscape-level issues, marine biology, vegetation, and water quality. The objective of these working groups is to gather information and generate topical reports summarizing monitoring-related information in detail (see Appendix A). These topical workgroups also played a key role in identifying, reviewing, and refining Vital Signs for the parks and network. The topical workgroups are headed by Technical Committee members and include Pacific Cooperative Studies Unit (PCSU) facilitators, NPS staff, and external scientists.

1. Designing an Integrated Monitoring Program for the PACN

Vital Signs monitoring is one of 12 components of the Natural Resource Challenge. Launched in 2000, the Natural Resource Challenge is a major program to revitalize and expand the natural resource program within the NPS and to improve park management through greater reliance on scientific knowledge. One of the primary goals of the Vital Signs monitoring program is to facilitate communication, coordination, and collaboration among parks, programs, academia, and other government agencies. The integrated monitoring program can be viewed as an information system: a key aspect of resource management and developing institutional knowledge. The steps involved in planning, designing, and implementing resource monitoring are like pieces of a puzzle; the entire system must be designed together for all the pieces to fit (Figure 1.4). Thus, Vital Signs monitoring is a partnership among parks, programs, federal and state agencies, universities and other organizations to develop and implement an integrated program to provide the scientific information needed to protect and manage the national parks.

[1] http://www.nature.nps.gov/im/units/pacn/pacn_charter.doc

Figure 1.4. Development of the Vital Signs monitoring program involves interconnected facets of collaboration, coordination, and communication.[1]

One of the most difficult aspects of designing a comprehensive monitoring program is integration of monitoring projects so that the interpretation of the entire monitoring program yields information more useful than that of individual parts. Integration involves ecological, spatial, temporal and programmatic aspects, as outlined below.

- *Ecological Integration* aims at incorporating the ecological linkages between system drivers and the components, structures, and functions of ecosystems when selecting monitoring indicators (i.e., marine, freshwater, terrestrial, or atmospheric). An effective ecosystem monitoring strategy will employ a suite of individual measurements that collectively monitor the integrity of the entire ecosystem. One approach for effective ecological integration is to select indicators at various hierarchical levels of ecological organization (e.g., landscape, community, population, genetic; Noss 1990).
- *Spatial Integration* involves establishing linkages of measurements made at different spatial scales within parks in the network, between individual parks in the network, and over a broader regional context. In many regards the Pacific Islands present a coherent geographic unit, however the sheer distances, differing continental proximity, and differences between northern and southern hemispheres provide challenges. Nevertheless, spatial integration requires understanding of scalar ecological processes, the co-location of measurements of comparably scaled monitoring indicators, and the design of statistical sampling frameworks that permit the extrapolation and interpolation of scalar data.
- *Temporal Integration* involves establishing linkages between measurements made at various temporal scales. It will be necessary to determine a meaningful timeline for sampling different indicators while considering characteristics of temporal variation in these indicators. For example, sampling changes in the structure of a tropical forest canopy (e.g., size class distribution) may require much less frequent sampling than that required for detection of changes in the composition or density of herbaceous

[1] *Modified from National Water Quality Monitoring Council.*

groundcover. Temporal integration may require nesting the more frequent and, often, more intensive sampling within the context of less frequent sampling.

- *Programmatic Integration* involves the coordination and communication of monitoring activities within and among parks, among divisions of the NPS, between other agencies and land management organizations, and among government authorities within the PACN region. For example, at the park level, the involvement of a park's law enforcement, maintenance, and interpretative staff in routine monitoring activities can garner wider support for monitoring, improved potential for involving and informing the public, and greater acceptance of monitoring results in the decision-making process. Coordination of monitoring planning, design and implementation with other agencies will promote sharing of data among neighboring land managers, while also providing context for interpreting the data.

2. Network Approach to Planning

Within the PACN, there is a long tradition of sharing technical resources or staff expertise to help all the parks best manage their resources. The network approach is a logical extension of this tradition. However, geographical, political, ecological, and other resource considerations vary considerably within the network, and a single monitoring plan encompassing all the network parks presents many challenges that the tradition of sharing skills and abilities has not previously addressed (e.g., documenting common ecological considerations and management concerns in a public, scientific, or peer-review setting).

As a Natural Resource Challenge funded program, the NPS Inventory and Monitoring Program has extensive guidance for preparation and implementation[1]. This approach includes seven steps for developing a network monitoring program:

1. Form a network Board of Directors and a Science Advisory committee.
2. Summarize existing data and understanding.
3. Prepare for and hold a scoping workshop for input and peer review of existing information and understanding of park ecosystems.
4. Write a report on the workshop and have it widely reviewed.
5. Hold meetings to decide on priorities and implementation approaches.
6. Draft the monitoring strategy.
7. Have the monitoring strategy reviewed and approved.

These steps are incorporated into a three-phase planning and design process established for the NPS monitoring program (Table 1.9). Phase 1 of the process is: a) defining goals and objectives; b) initiation of identifying, evaluating, and synthesizing existing data; and c) developing draft conceptual models. Phase 2 is selecting and prioritizing Vital Signs. In Phase 3, the monitoring plan is completed and implementation initiated.

[1] http://science.nature.nps.gov/im/monitor/

Table 1.9. Timeline for the PACN to complete the three-phase monitoring program planning and design process. Grey areas indicate when an item occurs.

	FY2001	FY2002	FY2003	FY2004	FY2005	FY2006
Anticipated Funding	*Inventory*	*Monitoring seed + inventory*	*Monitoring partial + inventory*	*Monitoring + inventory*	*Monitoring*	*Monitoring*
Data gathering internal scoping						
Inventories						
Scoping Sessions						
Conceptual Modeling						
Vital Signs Prioritization and Selection						
Protocol Development Monitoring Design						
Monitoring Plan Due Dates: Phases 1, 2, and 3				*Phase 1 Oct 2003*	*Phase 2 Oct 2004*	*Phase 3 Dec 2005 and Oct 2006*

The resulting monitoring plan, submitted in 2006, will be a first edition plan for the parks and network. The process of developing the plan, particularly the inventories and data mining, will provide a wealth of additional information to append the plan in future updates and revisions.

3. Workshops Held as Part of the Planning Process

Sessions to determine elements for consideration in the Monitoring Plan were held throughout 2002-2003 by network staff, the Technical Committee, and working groups. Table 1.10 identifies these meetings and provides links to meeting summaries.

Scoping Workshops were held with each of the PACN parks during 2002 and 2003 to help review and refine the conceptual ecosystem models and monitoring questions, and to identify ecosystem drivers and candidate attributes to monitor. The Technical Committee as a group remained involved in the sessions to provide continuity and ensure that all issues were considered. In addition, a workshop was held in 2001 at NPSA to identify marine Vital Signs in small parks. Additional workshops were held in 2003 and 2004 to receive input on the content and context of monitoring objectives and questions, Vital Signs, and conceptual models.

Table 1.10. Summary of scoping meetings and other workshops held to solicit input for monitoring plan.

Meeting / Workshop	Purpose	Date
Developing a Coral Reef Monitoring Program for NPSA - workshop[a]	Evaluate coral reef monitoring from a small park perspective	June 2001
Technical Committee Meeting	Establish monitoring objectives and working groups	June 2002
Park Scoping (all PACN parks)[b]	Solicit input from parks and cooperators on long-term monitoring	2002 and 2003
Conceptual Modeling Workshop[c]	Initiate development of conceptual models and identify desired future conditions	March 2003
Water Quality Planning Workshop[d]	Water quality components of the monitoring plan and its purpose were considered	August 2003

Meeting / Workshop	Purpose	Date
Technical Committee Meeting	Identify, review, and improve proposed Vital Signs	November 2003
Vital Sign Workshop[e]	Obtain NPS and external input (review) of proposed Vital Signs and priorities	March 2004

a. Developing a Coral Reef Monitoring Program for NPS – workshop products: http://www1.nature.nps.gov/im/units/pacn/monitoring/plan/2003-pre/vs_marine_npsa.pdf
b. Park Scoping products: http://www1.nature.nps.gov/im/units/pacn/monitoring/plan/2003-pre/scoping.htm. These scoping materials do not include USAR and ALKA as the PACN Board of Directors added these parks to the network after this effort was initiated.
c. Products of this workshop included the identification of desired future conditions for PACN parks and a draft structure for the conceptual ecological models.
d. Water Quality Planning Workshop products: http://www1.nature.nps.gov/im/units/pacn/monitoring/plan/2003-pre/waterq/index.htm
e. Vital Sign Workshop products: http://www1.nature.nps.gov/im/units/pacn/monitoring/plan/2004/vs04/index.htm.

4. Monitoring Objectives

Monitoring goals, objectives, and Vital Signs (see Chapter Three) illustrate the process the network has used to focus the monitoring program. Monitoring goals for the PACN are the five national goals listed in the beginning of Chapter One plus a sixth goal unique to the network. Broad monitoring objectives, identified below, ensure the identification of a full spectrum of ecological and management issues. Monitoring objectives will be refined and focused, yet remain broad enough to help facilitate partnerships to accomplish monitoring. Subsequent chapters of this monitoring plan will refine this focus through evaluation and selection of explicit objectives, methods, measures, and analytical techniques for individual Vital Signs.

Formulation of monitoring objectives has been an iterative process. We first articulated monitoring objectives from the suite of proposed Vital Signs, adjusted them to reflect the ecological organization outlined in Table 1.11, and added objectives or questions that were missing.

Table 1.11. Original ecological organization of PACN Vital Signs.

<table>
<tr><th>Ecological Characteristic</th><th colspan="3">Vital Sign Category</th></tr>
<tr><td rowspan="5">Human activities and cultural practices</td><td colspan="3">Soundscapes</td></tr>
<tr><td colspan="3">Viewscapes / Lightscapes</td></tr>
<tr><td colspan="3">Land Use</td></tr>
<tr><td colspan="3">Park Use and Activities</td></tr>
<tr><td colspan="3">Management Zones</td></tr>
<tr><td rowspan="5">Physical and Chemical Conditions</td><td colspan="3">Climate and Air Quality</td></tr>
<tr><td colspan="3">Soil, Water, and Nutrient Dynamics</td></tr>
<tr><td colspan="3">Water Quality</td></tr>
<tr><td rowspan="2" colspan="2">Geology</td><td>Hazards</td></tr>
<tr><td>Landforms</td></tr>
<tr><td rowspan="6">Biotic Integrity</td><td colspan="3">Overall Richness of Threatened & Endangered Species and Species of Concern</td></tr>
<tr><td rowspan="4">Freshwater Ecosystems</td><td rowspan="2">Producers</td><td>Community</td></tr>
<tr><td>Population</td></tr>
<tr><td rowspan="2">Consumers</td><td>Community</td></tr>
<tr><td>Population</td></tr>
<tr><td>Terrestrial</td><td>Vegetation</td><td>Landscape</td></tr>
</table>

Ecological Characteristic	Vital Sign Category		
	Ecosystems		Community
			Population
		Consumers	Community
			Population
		Cave Systems	Community
	Marine Ecosystems	Landscape	
		Community	
		Population	

In May 2004, after we developed our initial list of potential Vital Signs, the National Monitoring program distributed a Vital Signs framework that all networks were required to use to promote communication, coordination, and collaboration among the networks and with other agencies. Our monitoring objectives are presented in this framework in Table 1.12.

Table 1.12. PACN monitoring objectives, organized in the Inventory and Monitoring Program national Vital Signs framework.[1]

Level 1	Level 2	Monitoring Objective
Air and Climate	Air Quality	Determine spatial and temporal patterns and trends in atmospheric particulates, gases, and deposition.
		Track trends in sight distance and light extinction affecting visibility.
	Weather	Track the range of variation in weather patterns across PACN parks.
	Geomorphology	Document short- and long-term changes in coastal, stream, and dune morphologies.
	Subsurface Geologic Processes	Understand spatial and temporal patterns and variation in volcanic and seismic activity.
		Track changes in cave and lava tube environmental and morphological characteristics.
Geology & Soils	Soil Quality	Track physical, chemical, and biological changes in soils.
	Hydrology	Track spatial and temporal patterns and variation in hydrology of freshwater and marine systems.
		Determine magnitude and trends of water withdrawal for human use.
	Water Quality	Track spatial and temporal patterns and variation in water quality in freshwater and marine systems
Biological Integrity	Invasive Species	Use monitoring data for early detection & predictive modeling of incipient invasive species.
		Document changes in established populations of invasive species, including response to treatment.
	Infestations and Disease	Determine trends in incidence of disease and infestation in selected communities and populations.
	Focal species or Communities	Determine trends in composition, structure, and function of populations of selected focal species within the parks.
		Determine trends in composition, structure, and function of selected focal communities within the parks.
	At-risk Biota	Determine trends in populations of threatened, endangered, and at-risk species within the parks.
Human Use	Point Source Human Effects	Use monitoring data to determine patterns of litter and debris within parks and identify possible sources.
	Consumptive Use	Determine magnitude and trends in harvest of biological resources and sand.

[1] *This organizational framework will replace that shown in Table 1.10 for PACN Vital Signs.*

Level 1	Level 2	Monitoring Objective
	Visitor and Recreation Use	Determine spatial and temporal patterns of visitor use of park resources.
		Determine trends in levels of artificial light and shading in selected areas.
Ecosystem Pattern and Processes	Fire	Determine spatial and temporal patterns and effects of fire on vegetation communities.
	Land Use and Cover	Determine spatial and temporal patterns and changes in land cover and community distribution.
		Determine spatial and temporal patterns and changes in marine benthic cover and community distribution.
		Determine spatial and temporal patterns in land use and effects on park resources.
		Determine spatial and temporal patterns in marine use and effects on park resources.
		Determine whether viewshed features (landscapes and underwater seascapes) are changing within and surrounding the park.
	Soundscape	Determine trends in natural and anthropogenic sounds in selected areas.
	Nutrient Dynamics	Determine rates of nutrient turnover in terrestrial and aquatic systems.

5. Development and Selection of Vital Signs

Development and selection of the set of Vital Signs for initial implementation has been a multi-stage process, and will be ongoing as protocol development begins and monitoring is implemented. The first step in Vital Signs development defined goals and objectives of the monitoring program, reviewed available information about park resources, ecosystems, stressors, and concerns, and identified key characteristics of ecosystem integrity.

In the second step, we conducted thorough literature reviews, constructed conceptual models of ecosystem function, and developed an initial list of proposed Vital Signs for each topic area, as well as those that applied across broader scales. During this stage, we also solicited advice from the scientific community concerning key ecosystem attributes within particular ecosystems or topic areas. The next step involved refining proposed Vital Signs based on the input received, restructuring our conceptual ecological framework to comply with the national framework, and creating new Vital Signs to fill gaps identified during this stage. The fourth step required evaluating and prioritizing proposed Vital Signs for each park using the criteria in Table 3.1, and reducing the number of proposed Vital Signs based upon these priorities.

A draft short list of Vital Signs has been developed, along with a wait list for future consideration. These Vital Signs will be discussed at a November meeting of the selection committee, which will use the prioritized lists and other criteria (e.g., availability of existing protocols) to select the Vital Signs for initial implementation. Similar Vital Signs will be grouped to facilitate efficient protocol development. Additional detail on the process and criteria for ranking and selecting Vital Signs is found in Chapter Three.

6. Summary of Monitoring and Research Needs Within and Surrounding the Network

The following section summarizes general monitoring and research needs in the Pacific Islands Network. Detailed information on monitoring and research needs, potential partners for monitoring, and current monitoring projects in the parks can be found in appendices A and E, B and E, and C respectively.

Invasive species are a major problem throughout the PACN. Research and monitoring priority should be given to alien plant, vertebrate, and invertebrate species that are present or potential threats to more than one park unit. The levels of occurrence of marine invasive species and their effects on community structure are not fully understood and remain a research need throughout the PACN region. Terrestrial and freshwater invasive species biology is also not entirely understood, even for species being controlled in large segments of the parks. Nevertheless, continued monitoring and tracking of established and incipient invasives is a high priority in all parks.

Endangered species, species of concern (SOCs) and other rare species are found throughout the PACN, including plants, mammals, birds, insects, and snails. Although species with legal protection have the highest priority, many more species are known to be endangered than are currently listed. Monitoring should begin for these species before it is too late.

Research is needed on the ecology of unique ecosystems, such anchialine pools and lava tube communities. For example, research is needed on the effects of upslope development on groundwater quality as it affects anchialine pools and coastal wetlands. Even the community composition is not fully known for many of these habitats. Research on nutrient cycling and nutrient dynamics in both the terrestrial and aquatic environments in the PACN is also required. Studies in Hawaii on soil nutrient dynamics are ongoing (e.g., Vitousek 1995), but very little research has been conducted on nutrient cycling within freshwater or marine aquatic environments.

Relatively little terrestrial or freshwater monitoring or research has been carried out in the parks of the Western and South Pacific, although some parks are currently developing marine monitoring programs. As a result, research may be needed to develop statistically valid monitoring protocols applicable to a wide range of communities, populations, environments, and sampling questions. These may involve pilot studies to determine proper sample size and monitoring design. In addition, protocols from Hawaii or mainland parks or other agencies may be adaptable to local needs.

Before monitoring can commence, research identifying focal or indicator species will be needed to develop efficient monitoring programs for the different environments found in the parks. Many indicator or focal taxa for plants, fish, insects, and snails are already well known; others may be identified as monitoring expands into less well-studied ecosystems.

Various water quality studies are in progress or are being planned to assess conditions at or near PACN parks. Few of these programs involve long-term monitoring plans and even fewer are comprehensive in scope. Most study areas are outside of park boundaries and may have only one sampling location. In general, adjacent monitoring projects are non-NPS and specific to one resource issue, usually related to human health. In areas where sufficient baseline data exists, benthic algae or invertebrates are often used as indicators of trends in water quality. Some work on the relationship between organisms and fresh water quality has been done in the PACN region (e.g., Zolan 1981, Anthony et al. 2004), but more research is necessary to make these comparisons within the PACN. Identification of these relationships also needs research in the marine environment.

D. CONCLUSION

National Park Service enabling legislation mandates protection, preservation, and conservation of park resources, necessitating knowledge of status and conditions of park resources. Through natural resource monitoring, managers can understand and identify normal limits of natural variation in park resources, changes, and causes of change. Thirty-two National Park Service Inventory and Monitoring Program networks have been established, to provide baseline resource information and long-term trends in the condition of National Park System resources. With parks located throughout the Pacific, the PACN contains 11 parks and is the most extensive network in the NPS Inventory and Monitoring Program. Monitoring for PACN includes service-wide goals; however, PACN differs from other networks by including a cultural resource goal.

While the PACN parks share many characteristics, the vast geographic network includes varying species and habitats. Resources include freshwater resources (surface water, streams, wetlands, lakes, anchialine pools), marine resources (coral reefs, seagrass communities, coastal and strand communities), and terrestrial resources (native-dominated wet forest, native-dominated dry forest and grassland, alien-dominated wet forest and alien-dominated dry forest and grassland, alpine desert and subalpine scrubland, caves and lava tubes, lava fields and non-alpine desert, and predator-free offshore islets). Resources are affected by active volcanic processes. PACN contains a high proportion of threatened and endangered species. Main stressors to park resources are invasive species, adjacent land /resource use, fire, in-park use, and natural hazards. Global threats include sea temperature increase.

Vital Signs monitoring is a partnership among parks, programs, federal and state agencies, universities and other organizations to provide the scientific information needed to protect and manage the national parks. While there is a tradition of sharing technical resources or staff expertise to help all the parks in the PACN best manage their resources, geographical, political, ecological, and other resource considerations vary considerably within the network, and a single monitoring plan encompassing all the network parks presents many challenges that the tradition of sharing skills and abilities has not previously addressed.

The PACN includes many habitats and species that do not exist in other National Parks and therefore are important for national and even global conservation. Outlined plans and goals will lead to preservation of resources and knowledge about resource change. One of the first tasks in accomplishing these goals is to develop conceptual models of PACN ecosystems and processes. Chapter Two provides these conceptual models which illustrate components and interactions of PACN systems. Chapter Three describes the process of Vital Signs identification and selection, and presents a short list of high-priority Vital Signs.

CHAPTER 2. CONCEPTUAL MODELS

A conceptual model is a visual or narrative summary that illustrates the important components of a system and the interactions among them. Conceptual models represent current knowledge of the processes occurring in systems, illustrate system dynamics, identify the bounds and scope of the systems of interest, and provide a framework for testing hypotheses about how they function. No one "correct" model can be established; conceptual models represent the current best understanding of system dynamics, and should be refined as our understanding of ecosystem processes increases.

A. INTRODUCTION

Conceptual models simplify the organization and communication of information about ecosystem structure, function, and composition. The understanding gained from defining and testing such models can be applied to park management. A conceptual ecological model also ties parks in a network together by illustrating their common similarities. The PACN parks share a suite of characteristics that make them unique within the NPS, and highly threatened ecologically.

The complexity of natural systems, the differing scales, and the wide range of factors that influence them makes modeling a highly useful tool when developing a monitoring program. Differing scales and levels of detail can be incorporated into specific models to clarify these factors. The conceptual model also provides an objective and structured framework for selecting specific attributes (Vital Signs) to monitor.

To create a general conceptual ecological model for the Pacific Islands, a workshop was held in March 2003 with the goal of identifying key components, concepts, and cohesive principles that could apply to all network parks. The result was a first draft of the conceptual model for the PACN Phase 1 monitoring plan. An interdisciplinary group of NPS staff, regional NPS cooperators and partners, and university scientists participated in the workshop. Input from the PACN Technical Committee and other NPS staff in November 2003 was used to refine the model structure and components. The process of conceptual model development and refinement is designed to be ongoing as the program is developed, and will be especially important during the protocol design phase of the plan (FY 2005-2006).

B. GENERAL CONCEPTUAL MODEL

An **ecosystem** is defined as the biotic and abiotic components within a spatially explicit area and the interactions between them. **Ecosystem integrity** implies the presence of appropriate species, populations and communities, the occurrence of ecological processes at appropriate rates and scales, and environmental conditions that support these taxa and processes. The overarching goal of the NPS is the restoration and maintenance of ecosystem integrity within park boundaries (NPS 2001: 31). The PACN conceptual model combines the concept of ecosystem integrity with the interactive-control ecosystem sustainability model described in the next section.

In general terms, ecosystem models contain three complementary parts: ecosystem composition, ecosystem structure, and ecosystem function. Natural systems have considerable variation due to both stochastic events and successional change (Chapin et al. 1996). It is important to differentiate between intrinsic variability of natural systems and human-induced changes when monitoring ecosystem integrity. Ecosystem stability is maintained when natural variation in ecosystem components is not pushed into a new state by an introduced disturbance such as addition of nutrients, invasion by an exotic species, or increase in frequency of fire (Chapin et al. 1996). With recent large-scale changes in ecosystems in the Pacific region, questions of stability in ecosystem state are increasingly important.

The purpose of the formulation of the PACN conceptual ecological model is to prepare for the selection of monitoring priorities. In order to establish a diverse monitoring program that addresses multiple scales of issues, we strive to identify Vital Signs (and monitoring objectives) in each of the following broad categories:

- Ecosystem drivers that fundamentally affect park ecosystems.
- Stressors or threats and their ecological effects.
- Focal resources of parks.
- Key properties and processes of ecosystem integrity.

Clearly defined terms are necessary in any model to facilitate understanding of its components and interactions, as well as to aid in communication among individuals with diverse backgrounds and areas of interest. Terms adopted by the Inventory and Monitoring Program as a means of identifying ecosystem processes and components throughout the National Park System are defined in the Glossary. Symbols used to illustrate these components in graphical conceptual models are explained in the Glossary as well.

1. Pacific Island Ecosystems

Our general conceptual model has been developed, in part, to illustrate the broad characteristics of Pacific Island ecosystems. Natural Pacific Island ecosystems are often considered remarkable for the high levels of endemism exhibited by their flora and fauna. The Hawaiian Islands, for example, have been referred to as “the best ‘natural laboratory’ for evolutionary studies in the world” (Kaneshiro 1989), and contain a high proportion of the natural biological resources of the United States (Loope 1989).

In terrestrial and freshwater habitats in the Pacific Islands, there are often fewer native species or functional groups than are found in most continental regions, because relatively fewer species have managed to colonize the islands (e.g., Keast 1996). This phenomenon is also referred to as ‘disharmonic fauna’, where whole groups, such as most mammals or amphibians, are lacking from communities. Despite low numbers of colonizing species, a high level of biodiversity is found when many endemic species are present, as in the Hawaiian Islands (Loope and Gon 1989). Older islands tend to have higher levels of endemism than younger islands, and islands farther from source populations tend to have higher levels of endemism than those near source populations (Font 2003). High levels of endemism can arise from both evolution of single species in isolation and from adaptive radiations, where multiple species are derived from a single ancestral species; both of these mechanisms have occurred among the native species of the PACN (e.g., Keast 1996, Polhemus and Asquith 1996, Brasher 2003).

These patterns are well documented for terrestrial ecosystems, though differences exist among ecological and taxonomic groups (e.g., van Balgooy et al. 1996, Munroe 1996). Marine and freshwater systems have similar relationships. For example, numbers of Pacific reef fish species are highest near their source populations in Indo-Malaysia (Figure 2.1). Endemism tends to show the opposite pattern, with numbers of endemic species often increasing with distance from a population source (e.g., Munroe 1996, Font 2003). These examples illustrate the importance of understanding biodiversity patterns and dynamics within the PACN and how impacts from invasive alien species could alter these ecosystems.

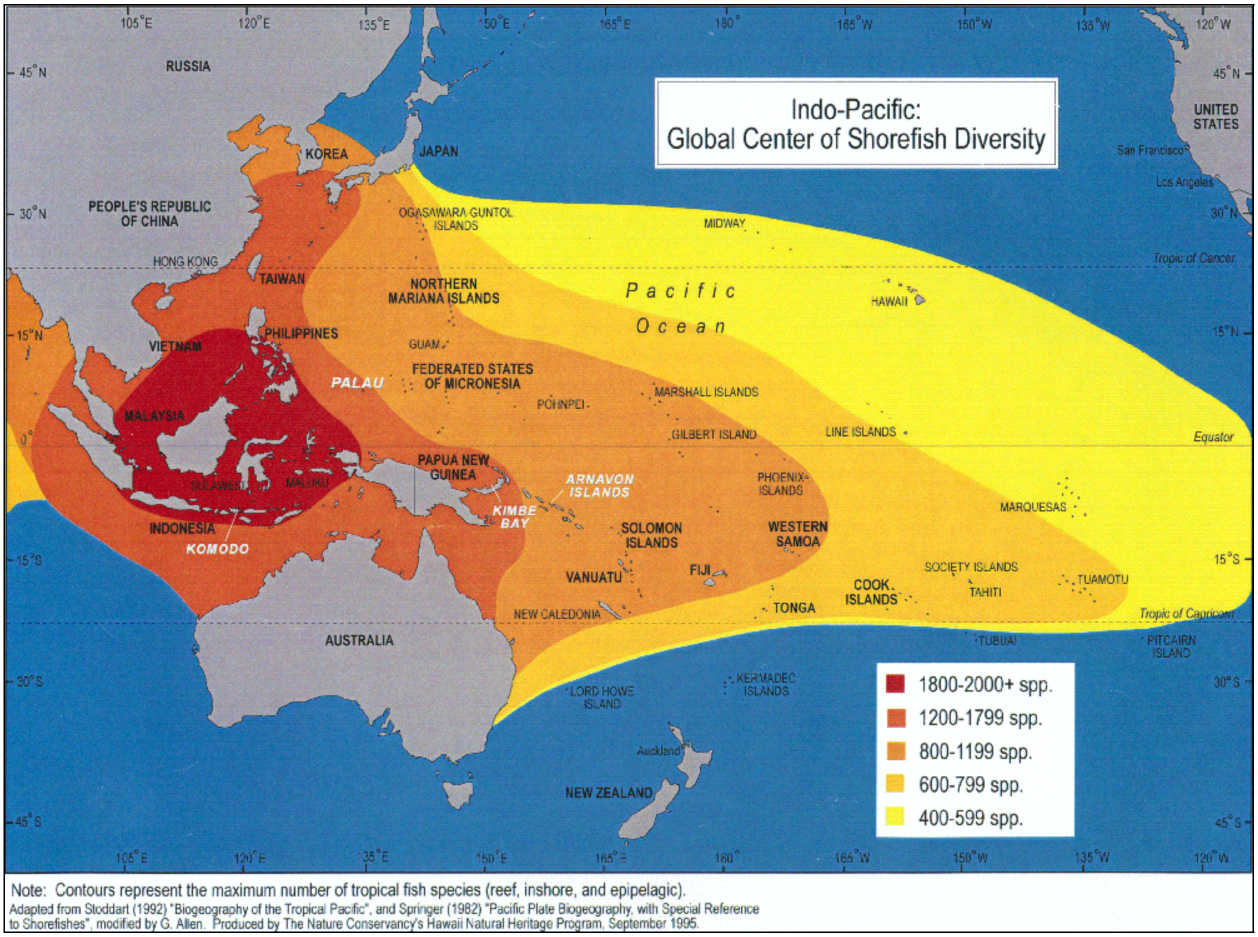

Figure 2.1. Patterns of reef fish biodiversity in the Pacific. Contours represent the maximum number of tropical fish species (reef, inshore, and epipelagic). [1]

One 'drawback' of high levels of endemism is that oceanic islands are exceptionally susceptible to biological invasions (Loope and Mueller-Dombois 1989, Denslow 2003). There is a strong correlation worldwide between percentage of biotic endemism and vulnerability of the biota to being displaced by biological invaders (Loope and Mueller-Dombois 1989). The presence of underutilized ecological niches, coupled with the ready accessibility of many habitat types from ports of entry and the moderate and stable climate, facilitates the establishment of alien species. In many cases, it seems that new introductions, whether accidental or purposeful, meet less resistance and have proportionately greater negative effects on Pacific Islands than in continental settings (Denslow 2003).

2. Hierarchical Model Structure

Ecological components, structure, and function must be integrated across varying spatial and temporal scales in any monitoring program. Therefore, we have developed a nested hierarchy of

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[1] *Adapted from Stoddart (1992) "Biogeography of the Tropical Pacific" and Springer (1982) "Pacific Plate Biogeography, with Special Reference to Shorefishes", modified by G. Allen. (with permission from Hawaii Natural Heritage Program).*

conceptual models for the PACN. This organization of conceptual models (Figure 2.2) proceeds from a large-scale simple model to several smaller-scale detailed models. General models facilitate communication among scientists, managers, and the public. Specific models are useful for identifying indicators (Vital Signs) and for management of site-specific issues.

The first level of model organization is a generalized ecosystem model, which incorporates an ecosystem sustainability model and models of the interactions among ecosystems and stressors on an idealized high Pacific island. At the next level of model organization are individual ecosystem and topical models. At the smallest-scale level of organization are ecosystem process and component models.

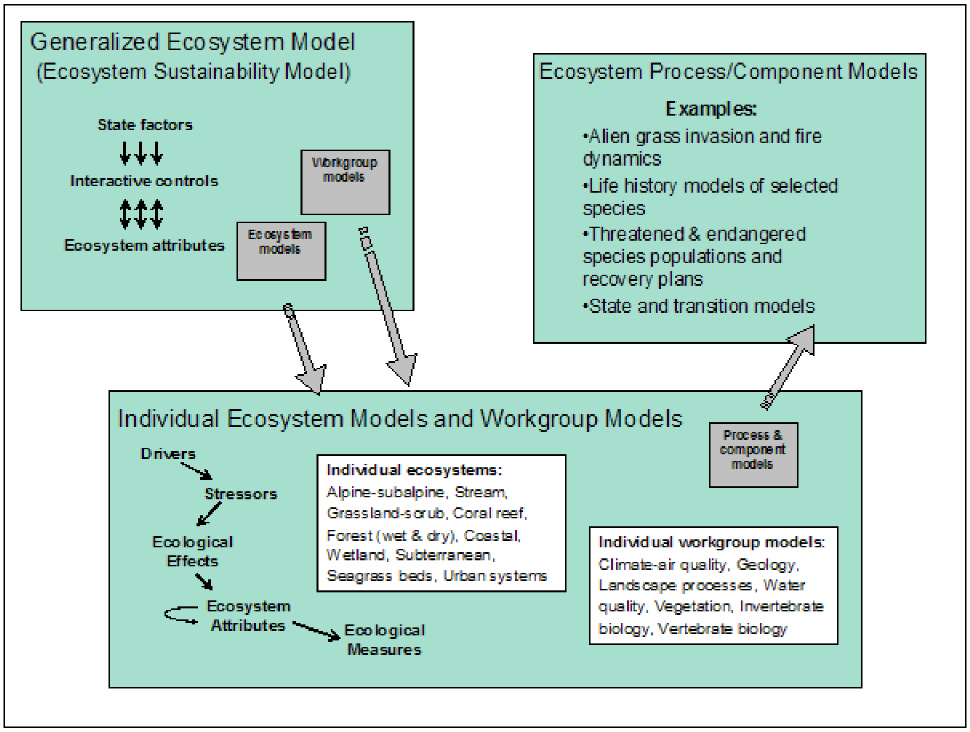

Figure 2.2. Hierarchical relationships between model types.

3. Ecosystem Sustainability Model

The PACN has adopted a modified version of the Jenny-Chapin "interactive-control" model (Figure 2.3), which is an ecosystem sustainability model that emphasizes both internal interactions and external factors (Chapin et al. 1996, Eveden et al. 2002). In this model, *state factors* (variables with independent variation that function as ultimate controls on ecosystem processes) include parent material, time since disturbance, climate, potential biota, and topography. These state factors influence *interactive controls* (which respond dynamically to each other and both influence and respond to ecosystem processes), which include local climate, soil or water resource supply, functional groups of organisms, and disturbance regime.

Evenden et al. (2002) replaced the interactive control *soil or water resource supply* with *soil or water resources and conditions*. This term is more specific when using interactive controls as a basis for selecting Vital Signs for monitoring. The PACN has also modified the *parent material* state factor to *parent material or water supply* for clarity when considering aquatic ecosystems. In this model, *ecosystem processes* include the three factors of composition, structure, and function that operate within an ecosystem (e.g., community composition, successional change, rate of nutrient cycling, and others). Figure 2.3 illustrates the modified PACN interactive-control model; state factors outside the circle are variables which operate outside the ecosystem bounds and control ecosystem processes, while interactive controls within the circle are variables which occur within the ecosystem and both control and respond to ecosystem processes.

The interactive-control model focuses on interacting ecosystem processes, and thus provides a framework for understanding large-scale ecosystem components. However, selection of monitoring priorities is not limited to processes. For example, monitoring of threatened and endangered species will be included because these organisms are identified as important ecological, and in some cases cultural, resources.

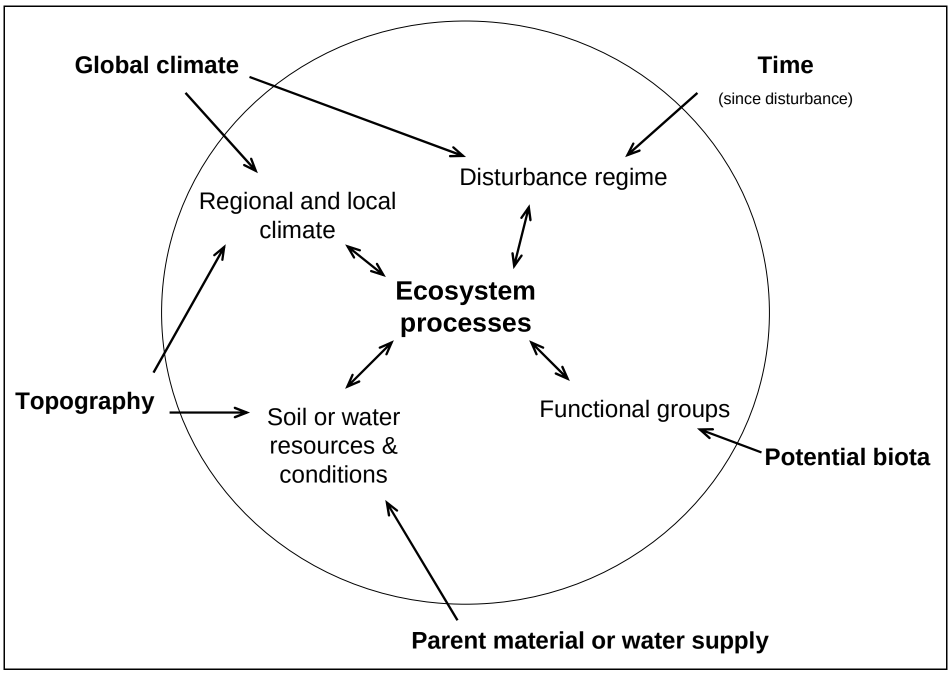

Figure 2.3. The Jenny-Chapin interactive-control model (modified from Evenden et al. 2002; see text for additional details).

a. State Factors

State factors are major forces of change in ecosystems, and may be strongly influenced by human activity. They are considered ecosystem drivers. State factors and their use in the PACN are described below:

- *Global climate* accounts for much of the variation in ecosystem structure, productivity, and biogeochemistry (Chapin et al. 1996). Characteristic climate patterns include Central Pacific trade winds and Western Pacific monsoons. Other global climate factors include the El Nino-Southern Oscillation (ENSO) cycle, which strongly influences climate on a three to four-year period and changes rainfall and temperature patterns across the Pacific (e.g., Chu 1989). In addition, global climate change is predicted to cause increased atmospheric and water temperatures, decreased rainfall, and sea level rise in the PACN region. Climate change may also lead to shifts in the trade-wind inversion and cloud lifting level as well as increased drought, thereby affecting cloud forests (high-elevation rain forests), which are a relatively intact ecosystem type in the PACN region (Loope & Giambelluca 1998).

Marine, terrestrial, and atmospheric interactions are tightly coupled. The global climate state factor includes aquatic oceanic climate as well as atmospheric conditions. Oceanic climate influences near-shore marine ecosystems and terrestrial ecosystems. Sub-factors include global oceanic circulation patterns which influence the distribution of organisms, and more localized deep water mixing events which strongly affect nutrient availability and productivity.

- *Time since disturbance* includes both natural and human-caused disturbances. These include volcanic activity, fire, disease outbreaks, tropical cyclones, as well as forest clearing, chemical spills, and severe overfishing. Time since disturbance affects processes such as soil and reef formation, colonization by organisms (including invasive species), and recovery of communities from significant stress.

The history of the Pacific Islands presents an excellent opportunity to monitor the dynamics of ecosystem development over time (Vitousek 1995). For example, the Hawaiian Islands have a clear and well dated age progression; but American Samoa has a complex age matrix within a very small area. In many areas, the influence of human activity is also relatively well dated allowing comparison of the effects of natural and anthropogenic influences on community succession.

- *Potential biota* is the pool of species from which ecosystems are populated. These species may be either native or introduced. This distinction is significant in the PACN, as non-native species have replaced or threaten to replace natives in many areas. In the Pacific Islands, the number and type of potential species available for colonization was frequently small, so species that did colonize evolved to utilize different ecological niches in the process of adaptive radiation.

Patterns of native species diversity in several groups in the PACN vary with distance from Southeast Asia and Indonesia. Adhering to theories of island biogeography, the number of species present within several groups decreases with increasing distance from Indonesia, while the number of endemic species increases (see Fig. 2.1). Human activity has broken down geographic barriers to dispersal, so this pattern does not hold for introduced species.

- *Parent material or water supply.* Initial substrate composition has a strong effect on soil resources that eventually form. The islands of the PACN are volcanic in origin, formed by hot spot plumes in Hawaii and American Samoa and plate subduction in the Marianas. However, chemical composition of their lavas and ash differs (Vitousek 1995). Additionally, the limestone cap found in portions of the Northern Marianas forms a chemically different parent material.

Water supply is the analogous state factor in aquatic ecosystems. Water supply includes quantity of water, which determines presence and potential zonation of aquatic ecosystems. It also includes chemical makeup (i.e., salty or fresh, acidic or alkaline), and its sources (whether from groundwater or surface flows). Terrestrial parent material influences both freshwater and marine supply as solutes are transported through the system. In marine systems, this process is often strongly affected by groundwater intrusion or surface runoff.

- *Topography* varies significantly across spatial scales, and interacts with the state factors of *time* and *parent material*. For example, the Hawaiian Islands are shield volcanoes formed from variably-textured lava at small spatial scales, and are eroded into complex and rugged topography at broader scales. Landforms eventually erode and subside to form lower relief atoll topography. In the marine environment, corals build complex structures as islands and landforms age.

  Topography influences the interactive control of soil or water resources and conditions by determining potential soil or water depth and locations of sediment deposition. Regional and local climate is also affected by topography. For example, elevation influences patterns of wind, temperature, and rainfall on land, while current patterns, temperature, and light penetration are affected in aquatic systems.

b. Interactive Controls

Interactive controls generally operate inside the bounds of ecosystems, and are constrained by state factors. They change predictably as processes such as succession occur, though major changes can lead to significantly different ecosystems (Chapin et al. 1996):

- *Regional and local climate.* The PACN is located within the tropics and subtropics; however, nearly all the world's major climate zones are represented on the islands due to the interaction of global climate and topography. Global atmospheric circulation generally produces consistent trade winds, and a trade wind inversion layer is formed at approximately 2000 m. These interactions have the effect of producing striking local climatic gradients in temperature, precipitation, and deposition. The spatial and temporal distribution of climatic conditions help drive variation in ecosystems.

  In marine systems, local current regimes influence distribution of organisms, and upwelling conditions or groundwater intrusion affect productivity. Atmospheric climate also influences aquatic conditions, for example, rainfall determines the amount of water available to form freshwater systems, and also has an effect on sediment inputs to aquatic systems as it causes erosion.

- *Disturbance regime.* Within the PACN region, storm events (both tropical cyclones and periods of brief and intense rainfall) and earthquakes can significantly affect multiple ecosystems. Other natural disturbances that occur within PACN parks include stream flooding, tsunami, landslides, volcanic activity, wildfires, seasonal high wave events, coastal erosion, and drought. Blizzard conditions can occur in HAVO on the summit of Mauna Loa, and snow has occasionally fallen in HALE at the summit of Haleakala. Large-scale disturbances significantly interact with soil and water resources and conditions, as well as regional climate. In addition, localized disturbances such as landslides in a single watershed or the noise from boat motors may have profound impacts on organisms in a single area.

  Frequency and intensity of disturbance events strongly affect community composition and timing of ecosystem processes such as succession (Chapin et al. 1996). Human activity often modifies disturbance regimes on the Pacific Islands through such activities as diverting streams, which reduces both base flow and timing and severity of floods, introducing alien grasses, which increases the frequency and scale of fires, and clearing forest for agriculture, which changes patterns of nutrient cycling.

- *Functional groups* are able to influence ecosystem processes through modification of soil chemistry (N-fixing organisms), modification of spatial structure (reef-building corals), reduction of water flow (semi-aquatic plants), enhancement of erosion (ungulates), increase in disease occurrence (blood-sucking insects), and predation (carnivores). The presence of functional groups is influenced by local climate, soil and water resources, and disturbance regime (Chapin et al. 1996).

  The functional group interactive control does not explicitly distinguish between native and introduced species. However, pre-human Pacific Island ecosystems lacked certain functional groups (e.g., predatory terrestrial mammals, or fire-adapted grasses), whose introductions with human aid have been highly detrimental to native species (e.g., D'Antonio & Vitousek 1992). The distinction between native and introduced species is a significant factor in the principle of ecosystem integrity, which the PACN is combining with this ecosystem sustainability model. Therefore, PACN Vital Signs will include focal native and alien species or guilds, including but not exclusively those belonging to important functional groups.

- *Soil or water resources and conditions.* Soil resources and conditions determine both productivity and maximum structural diversity of plants (Chapin et al. 1996) on land. Resources include nutrient supply and moisture; other conditions include the presence of certain compounds (such as pesticides or heavy metals). Soil resources and conditions are influenced by the state factors of topography and parent material, as well as the presence of N-fixing organisms (Jenny 1941). In the case of volcanic substrates, which comprise much of the land in PACN parks, soil resources are also affected by time since substrate creation.

  In aquatic ecosystems, water resources and conditions are the equivalent interactive control (Chapin et al. 1996), influencing non-photosynthetic organisms, algae, aquatic plants, and corals. Water resources and conditions include both water availability and quality, including water flow, quantity of nutrients, light penetration, and presence of pollutants. Water resources and conditions are influenced by the state factors of parent material, water supply, and topography.

4. Idealized Pacific Island

Parks in the PACN share ecological and historical conditions that make them unique within the National Park Service. Figure 2.4 illustrates the ecosystem zonation of an idealized high-elevation Pacific Island, as it relates to altitude and characteristic rainfall patterns. Elevations of all PACN islands rise into the montane mesic/cloud forest or mid-elevation seasonal/rainforest ecological zones, while the islands of Maui and Hawaii also extend into the sub-alpine and alpine zones. Most parks occupy only a portion of the idealized island. Cave and lava tube systems may be located at any elevation.

Length of human presence on the islands in the PACN varies. The Mariana Islands, including Guam and Saipan, are thought to have been colonized about 3,500 years ago, as were the islands of Samoa. The Hawaiian Islands are thought to have been colonized only about 1,600 years ago.

European contact with the Marianas began about the 1650s, while contact with the Samoan and Hawaiian Islands began in the 1770s. The history of human activity varies among islands, but all have been significantly influenced by human use.

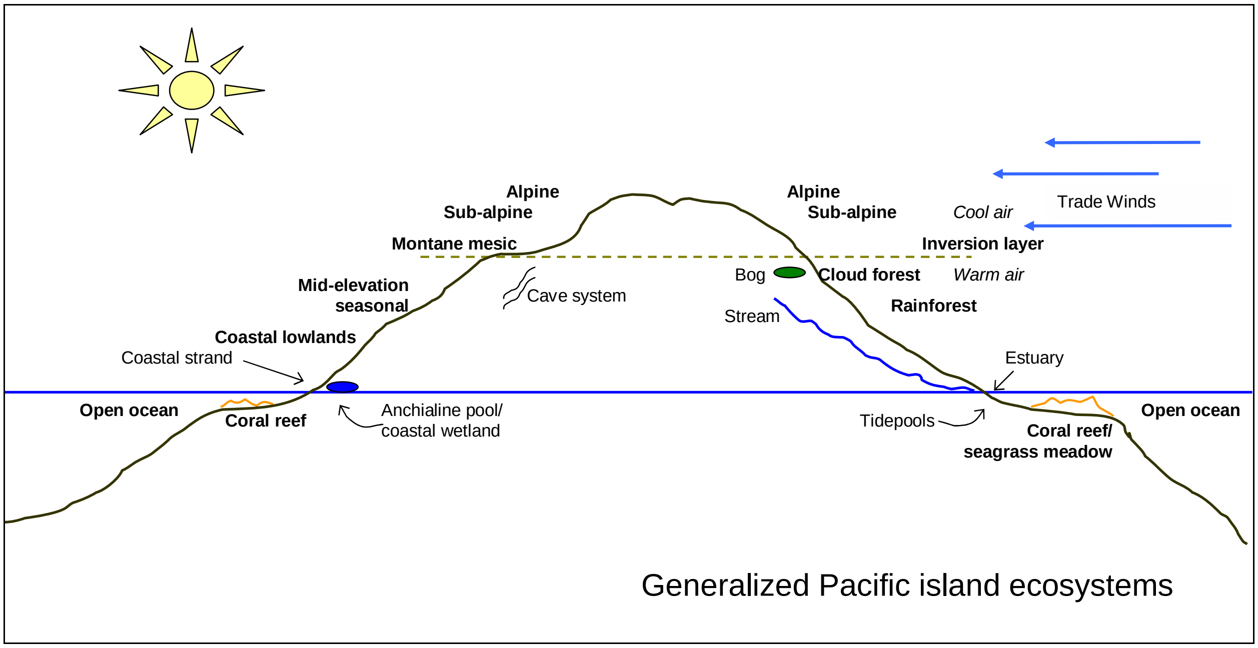

Figure 2.4. Idealized high-elevation Pacific island ecosystem zonation (modified from T. Tunison, pers. comm., NPS, and Juvik & Juvik 1998).

Ecosystems in the lower reaches of the idealized high Pacific Island (Figure 2.4) have been heavily altered by humans since first colonization (e.g., Burney et al. 2001), and anthropogenic impacts continue today at an accelerated rate. All habitat zones were used by native peoples to some degree, although the extent and exact nature of use is not fully known. Traditional uses and practices continue today in many National Parks, though more recent land use practices have for the most part superseded traditional cultural impacts on ecosystems.

a. Pacific Island Stressors

Pacific Islands share several primary stressors that arise from their small size and isolation, geological activity, and histories of human occupation. Common stressors arise from both natural and anthropogenic sources (Figure 2.5). These stressors are recognized to affect multiple ecosystems, and are often recognized as possible threats to human health or safety. They fall into several broad categories: geological hazards, global climate change, human population expansion and anthropogenic disturbance, and introduction of alien species.

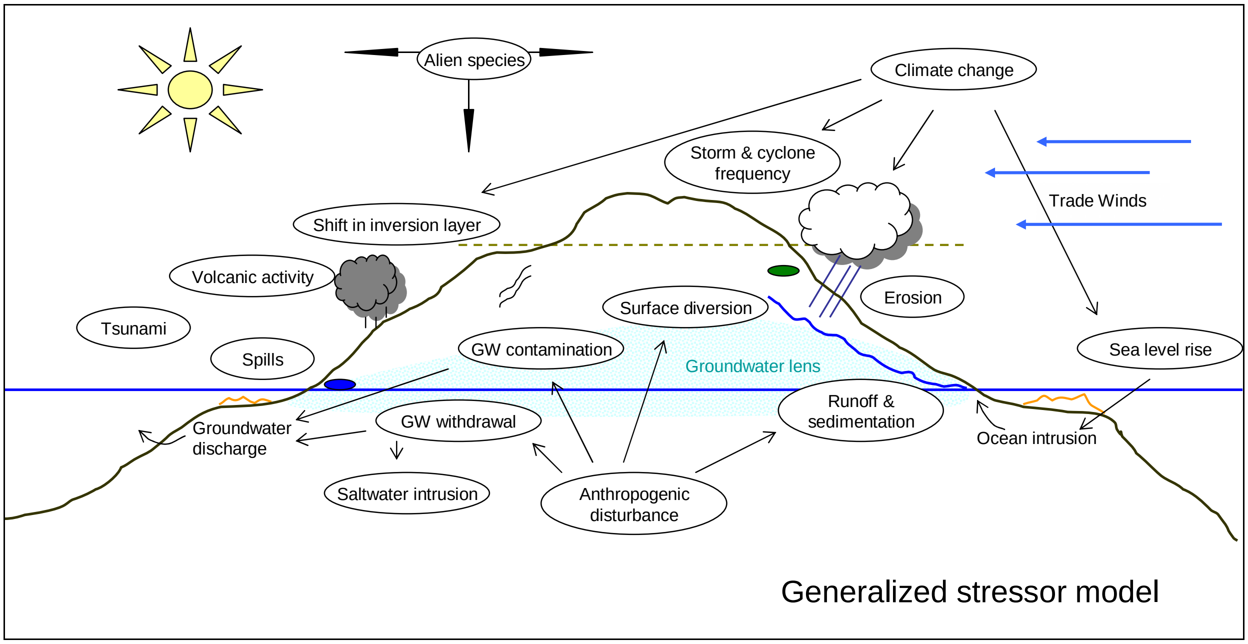

Figure 2.5. Generalized stressor model for most Pacific Islands and Pacific Island ecosystems. Alien species are illustrated as having the potential to impact all ecosystems. Ecosystems illustrated are identical to those in Fig. 2.4.

Invasive species already present in the islands comprise the most significant stressors for many ecosystems of Pacific island parks. The drivers for these stressors are various facets of land use and human activity, including the breakdown of biogeographic barriers through intentional or unintentional transport of biological organisms by humans. Such transport of organisms by humans is not decreasing; to the contrary, the process of globalization and species introductions is increasing (Vitousek et al. 1996). Therefore, species invasion will only be slowed in the immediate future by measures purposely implemented to prevent, detect, rapidly respond to, and manage invasions (Vitousek et al. 1997; Loope et al. 2001). Without special attention, invasions will continue to accumulate on Pacific Islands, with increasingly devastating results for resources of island parks.

b. Atmospheric, Terrestrial, and Marine Interactions

Links between the atmosphere, land, and marine systems are readily apparent on oceanic islands (Figure 2.6). Many of the terrestrial-marine linkages are mediated by freshwater systems, for example, transport of nutrients and organic matter from forests to coral reefs by streams. All terrestrial systems within the PACN are classified broadly as coastal systems, because of these interconnections.

Surface water and ground water systems are highly interconnected as well. Groundwater on Pacific Islands exists in a “lens” floating upon seawater, and all groundwater resources are formed by the percolation of rainwater into bedrock. Withdrawal of groundwater for human consumption often reduces the flow of streams and lowers the water table in wetlands, illustrating the interconnectivity of these resources. Additionally, freshwater springs may be found under the ocean surface; these springs provide a source of nutrients to nearby organisms.

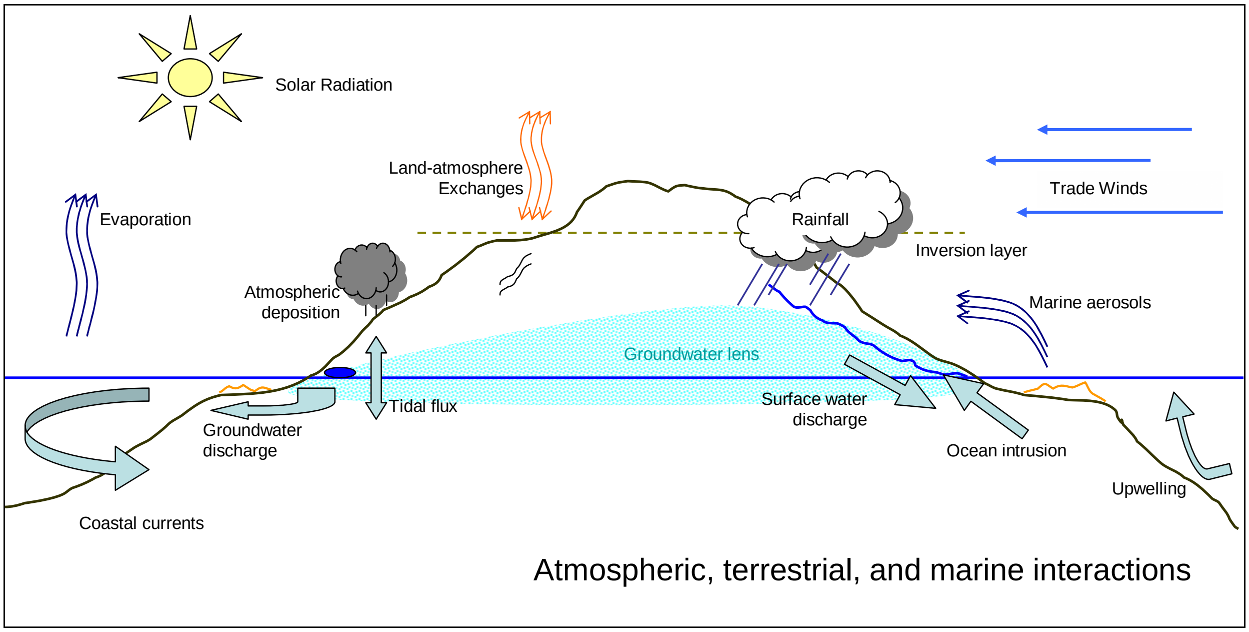

Figure 2.6. Atmospheric, terrestrial, and marine interactions, illustrating key linkages between the atmosphere and marine, freshwater, and terrestrial ecosystems. Ecosystems illustrated are identical to those in Fig. 2.4.

Within the generalized model of a high Pacific Island, a wide range of ecological and social conditions are present. Climate, topography, geology, human land use patterns, and native species composition vary greatly among islands and within parks. This variation leads to focused ecosystem-level conceptual models that can be applied to the appropriate parks.

C. Ecosystem Models

Not all islands contain all ecosystem types, and not all parks contain habitat representative of all ecosystems on an island (Table 2.1). However, parks such as NPSA, HALE, and HAVO contain resources ranging in elevation from uppermost elevations to the sea, including entire watersheds such as that of Laufuti Stream in NPSA.

Table 2.1. Ecosystems located within or immediately adjacent to PACN parks, with brief descriptions and parks in which they are found.

Ecosystem Type	Description	Parks[a]
Alpine and subalpine	High altitude, very low rainfall (above inversion layer). Scrubland and aeolian alpine desert.	HALE, HAVO
Forest		
Wet forest	Rain forest and mesic forest below inversion layer, cloud forest at inversion layer. Includes both native and alien systems.	WAPA, NPSA, KALA, HALE, HAVO
Dry forest	Dryland forest, both coastal and montane. Includes both native and alien systems.	HALE, KALA, PUHE, KAHO, PUHO, HAVO, ALKA
Scrubland and grassland	Mid- and low-altitude scrubland and grassland. Includes both native and alien systems.	WAPA, HALE, PUHE, KAHO, PUHO, HAVO, ALKA
Freshwater		
Stream	Flowing-water systems, includes sources, riparian areas, and estuaries. Both perennial and intermittent streams and seeps.	NPSA, WAPA, KALA, HALE

Ecosystem Type	Description	Parks[a]
Wetland	Montane bogs at high elevation, lakes, coastal wetlands and mangrove forest, anchialine ponds, man-made enclosed fishponds, upland and coastal springs. Includes both native and alien systems.	AMME, WAPA, KALA, HALE, PUHE, KAHO, PUHO, HAVO, ALKA
Marine		
Coral reef	Coral communities measured from shoreline to pelagic zone.	AMME, WAPA, NPSA, USAR, KALA, HALE, ALKA, PUHE, KAHO, PUHO, HAVO
Seagrass	Seagrass beds are located at Guam, Saipan, and Samoa parks.	AMME, WAPA, NPSA
Coastal	Includes sea cliffs, limestone and basalt rocky shores, sand and cobble beaches, and strand vegetation communities. Includes both native and alien systems.	all parks
Subterranean	Cave and lava tube ecosystems.	WAPA, HALE, KAHO, HAVO, ALKA
Urban	Parks or park units within or surrounded by extensively urbanized areas.	AMME, WAPA, USAR, ALKA

a. Resources of ALKA have not been inventoried, as planning for this trail is currently ongoing.

Ecosystems do not exist in isolation, but are linked by movement of air, water, and organisms (Polis et al. 1997). When establishing conceptual models to be used in the National Parks, it is important to make clear that all PACN parks, including those that do not contain all model components, interact with these components via processes that occur outside park boundaries. For example, coastal wetlands are influenced by zones of human activity outside of park boundaries through the movement of groundwater or streams into park boundaries. In Hawaiian coastal parks, mangrove seeds have been carried by ocean currents from nearby areas, allowing the establishment of this alien species within fishponds. This landscape-scale view of ecological processes emphasizes the need for interactive management partnerships with external agencies and organizations. With the exception of NPSA, none of the PACN parks' boundaries include an entire watershed from mountain to nearshore marine habitat. Most of the PACN parks contain either fragments of ecosystems within a watershed or, such as HAVO and HALE, end at the mean high-tide line and therefore abut marine ecosystems.

1. Stream Biology Ecosystem Model

The stream biology ecosystem model explained in Figure 2.7, shows the interactions between ecosystem components, attributes that may be used as Vital Signs, and the hypothesized effects of stressors on ecosystem attributes. It includes drivers, stressors, selected ecological effects of stressors, ecosystem attributes, and ecological measures. This model illustrates hypothesized interactions between stressors and proposed Vital Signs (ecosystem attributes), as well as important interactions among ecosystem attributes. For full text of the model, see the Freshwater Biology report in Appendix A.

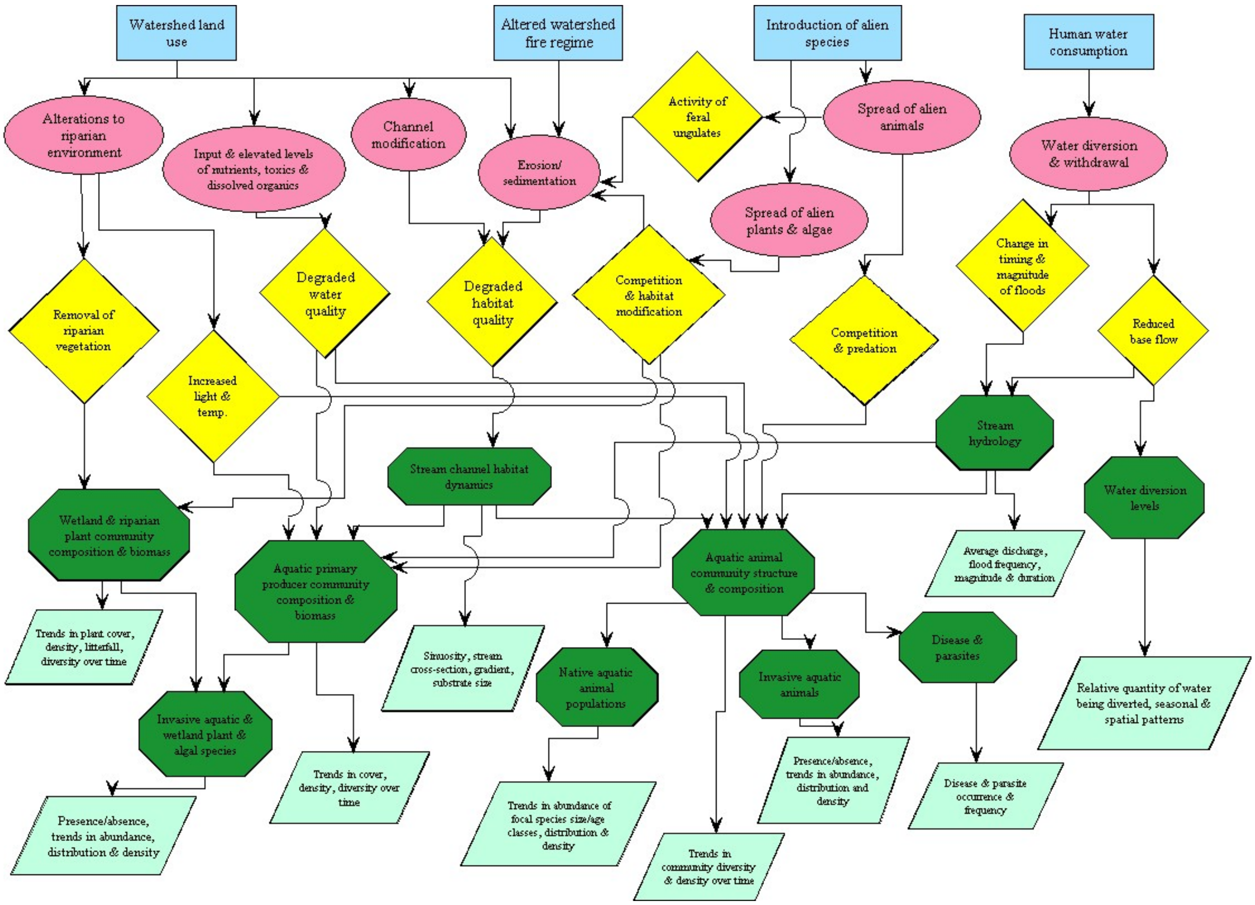

Figure 2.7. Stream biology ecosystem model. Symbols represent external drivers (rectangles), stressors (ovals), ecological effects of stressors (diamonds), ecosystem attributes or proposed Vital Signs (octagons), and ecological measures (parallelograms).

2. Other Ecosystem Models

A marine biology ecosystem model (see Marine report in Appendix A) has been constructed similarly to the stream biology model. Primary stressors of marine ecosystems (including coral reefs, seagrass meadows, and sediment flats) and their ecological effects on biological communities will be illustrated. This model applies in general to marine systems, however, certain stressors and their effects impact some systems more than others. For example, changes in coral/ algal dominance are very important in coral reef ecosystems, but not important in coastal mangrove swamps. The marine biology system model broadly illustrates the drivers and stressors common to marine systems, as well as selected resulting ecological effects.

A wetland ecosystem model has also been constructed which includes both coastal model and upland wetland models (see the Freshwater Biology report in Appendix A). The coastal wetland model includes mangrove wetlands, anchialine pools, fishponds, and other tidally-influenced water bodies. The upland wetland model includes upland bogs, ponds, seeps, and non-tidally-influenced wetlands. As with the marine model, ecological drivers and stressors affect certain ecosystems differently, for example, sea level rise is a significant stressor in coastal systems, but not in upland systems.

Topics for terrestrial ecosystem models are located within various topical reports (Appendix A). As part of the process of Vital Signs protocol development, other models which include terrestrial ecosystems will be constructed in the future.

D. Topical Workgroup Models

In addition to conceptual models of various ecosystems, models of ecological issues within different disciplines have been constructed by the topical workgroups as part of the reports (Table 2.2). As an example of a topical model, the water quality model is discussed below. Topical reports and models can be found in Appendix A.

Table 2.2. PACN topical workgroups and topical workgroup models.

Workgroup	Model(s)
Air quality and climate	Air quality and climate model
Data management	none
Freshwater biology	Stream biology and wetland biology (ecosystem models)
Geology	Geology model
Invertebrate fauna	Invertebrate fauna model
Landscape	Landscape model
Marine	Marine biology (ecosystem model)
Vegetation	Vegetation and flora model
Vertebrate fauna	Vertebrate fauna model
Water quality	Water quality model

1. Water Quality Model

The water quality model (Figure 2.8) is intended to help distinguish causal relationships between natural resources, human activity, and water quality. It encompasses water quality for all resource types (fresh, marine, and ground water), so represents a broad illustration of aquatic systems. The relative importance of issues and weight of effects are not demonstrated in the water quality conceptual diagram, but may be added later or used in more detailed models of specific water body types. Development of this model will help to promote expansion of resource conservation from traditional values of human health concerns to include resource sustainability.

In this model, drivers occur independently of one another, but may operate simultaneously, magnifying the effect of associated stressors on the ecosystem. In the water quality model, they include climate change, human use (including both terrestrial and aquatic activities), natural disturbance events, and the hydrologic cycle. Multiple stressors are mediated by a complex set of linkages, as system-specific stressors trigger a suite of ecosystem responses (Cloern 2001). This interaction between stressors and ecosystem responses is indicated in the conceptual model by placing stressors in a single box, which then initiates several categories of ecological effects. The model endpoints are various ecological measures which can be used to indicate ecological effects. For full text of this model, see the Water Quality report in Appendix A.

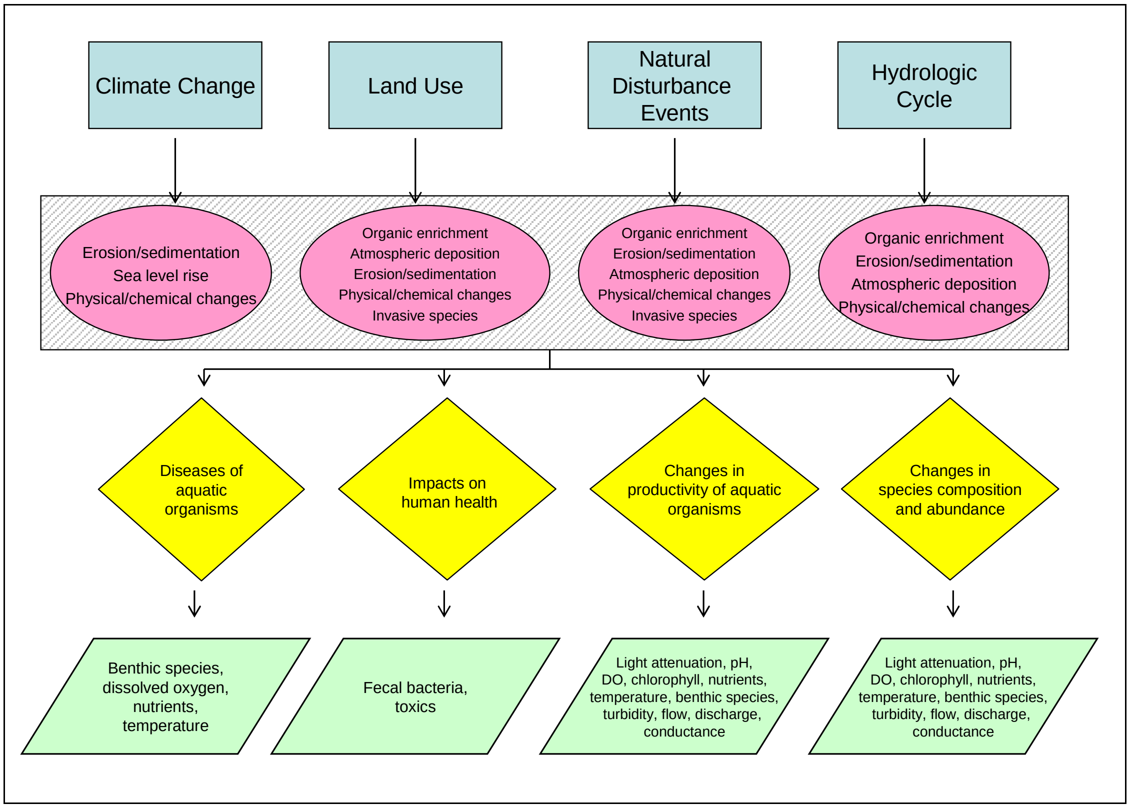

Figure 2.8. PACN Water Quality model, including marine, surface, and ground water. Symbols represent drivers (rectangles), stressors (ovals), ecological effects of stressors (diamonds), and ecological measures (parallelograms).

2. Other Topical Workgroup Models

Other topical models which have been constructed include air quality and climate, geology, terrestrial invertebrate fauna, landscape issues, terrestrial vegetation, and terrestrial vertebrate fauna. These models can be found in the appropriate topical reports in Appendix A. Because these topic areas vary significantly in scale and subject, formatting and presentation of these models varies.

E. Ecosystem Process and Component Models

These topical models demonstrate our understanding of selected ecosystem processes and components. They show in detail specific processes below the ecosystem level, such as life histories and habitat uses of focal species or the effect of nitrogen-fixing plants on community succession. These models are useful for communicating our understanding of specific processes to different audiences and elaborating on processes that are simplified in the depiction of ecosystem models. Emphasis on construction of ecosystem process and component models will be for funded Vital Signs.

Two types of process and component models are life history models, which illustrate timing and spatial locations of life history events of a focal species or guild, and state and transition models, which depict thresholds between possible states or phases and the mechanisms that may cause change in these states. Below are two examples, the amphidromous life history model alien grass/fire state and transition model.

1. Amphidromous Life History

A model of the amphidromous life history (Figure 2.9), which is shared by most native Pacific Island stream fish and macroinvertebrates, identifies life history stages (pentagons), illustrates spatial locations of natural system drivers (rectangles), and points of potential anthropogenic disturbance (ovals). Amphidromous species migrate between fresh and salt water at two points in their life cycle: from fresh to salt as larvae and from salt to fresh as juveniles (Fitzsimons et al. 2002). Preservation of amphidromous populations requires that a freshwater connection and appropriate ecological conditions and aquatic resources be maintained in a stream from the headwaters to the sea. Presence of alien species, development such as damming or channelization, and withdrawal of water act as stressors at different spatial locations.

This type of diagram illustrates the ecological needs of a specific group of organisms in relation to the different spatial habitats that they utilize during their life cycle. Its primary usefulness is in selecting strategies to monitor populations of species of concern or biological indicator species.

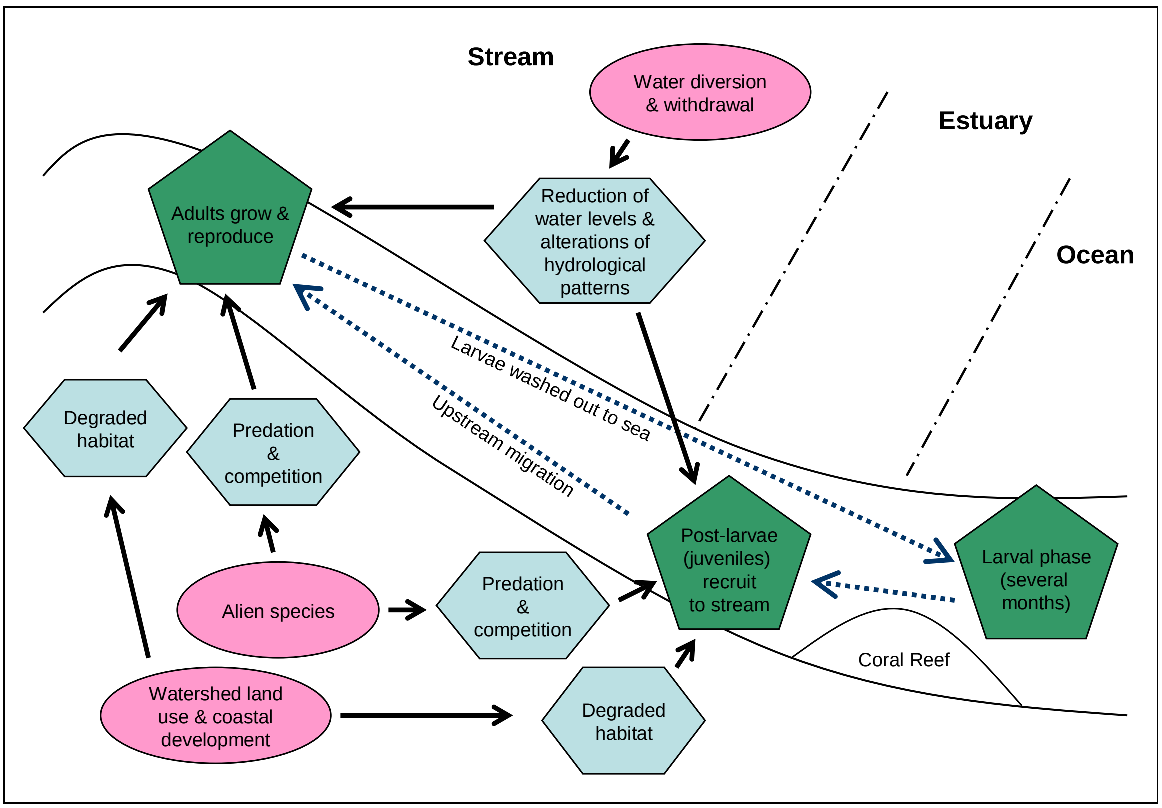

Figure 2.9. Amphidromy life history model, illustrating habitats in which life history stages occur (pentagons), potential anthropogenic disturbances (ovals), and effects of disturbances on organisms in each life history stage (hexagons).

2. Effect of Alien Grasses and Fire on Vegetation Structure

This state-and-transition model illustrates the effects of alien grass invasion and fire frequency on vegetation structure (Figure 2.10). This type of model is useful when examining the effects of human activity on specific ecosystem processes and includes possible management actions necessary to return the system to a previous state.

In an ecosystem originally dominated by woody vegetation, both land clearing and introduction of alien grasses can lead to an increase in fire occurrence and intensity. Fire leads in turn to a transition to a grassland or savanna ecosystem. This new ecological state is then maintained by ecological feedbacks promoting the continuance of frequent fires (D'Antonio and Vitousek 1992). A transition from the new state (grassland or savanna) to the previous state (woody vegetation) can only be effected by an intensive program of management and restoration.

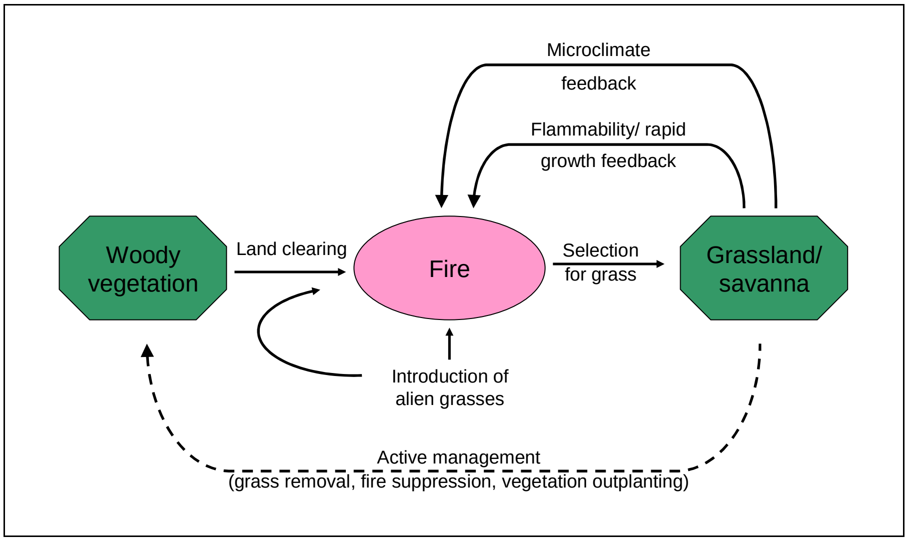

Figure 2.10. Conceptual illustration of alien grass invasion and fire frequency (modified from D'Antonio and Vitousek 1992). Stressors are represented by ovals, ecological effects by octagons. Dashed lines represent management actions required to return the system to the previous state.

F. Conclusion

Conceptual models simplify the organization and communication of information about ecosystem structure, function, and composition. Models demonstrate similarities between network parks and allow use of different scales and factors while developing a monitoring program. Knowledge from defining and testing such models can be applied to park management and provide a framework for selecting which Vital Signs to monitor.

The PACN uses a nested system of models to describe ecosystem process, components, and function. The primary conceptual model combines the concept of ecosystem integrity with Kenny-Chapin ecosystem sustainability model (Evenden et al. 2002). All PACN parks, including those that do not contain all model components, interact with these components via processes that occur outside park boundaries. This landscape-scale view of ecological processes emphasizes the need for interactive management partnerships with external agencies and organizations.

This report also describes ecosystem, topical workgroups, and process and component models. These models operate at smaller scales and are useful for communicating our understanding of systems and specific processes to different audiences during Vital Signs development and implementation. The PACN conceptual ecological models have been formulated to prepare for the selection of monitoring priorities. In order to establish a diverse monitoring program that addresses multiple scales of issues, Vital Signs will be selected in the categories of ecosystem drivers, stressors and threats, focal resources, and key properties and processes. In Chapter 3, details are provided for the prioritization and selection of Vital Signs.

CHAPTER 3. PRIORITIZATION AND SELECTION OF VITAL SIGNS

A. INTRODUCTION

A high priority for the PACN is to select Vital Signs that meet critical natural resource data needs, while meeting additional budgetary and logistical constraints. The NPS Water Resources Division (WRD) provides funds to the PACN for water quality monitoring and requires that the network determine priorities for impaired and pristine waters, define site-specific monitoring objectives, and develop a detailed water quality monitoring plan to be implemented in close coordination with Vital Signs monitoring. The PACN has chosen to fully integrate water quality monitoring with the remainder of the monitoring plan, and a description of how the aquatic Vital Signs were selected is also included in this chapter.

The purpose of this chapter is to present the Vital Signs identified as priorities for monitoring by individual parks and to discuss Vital Signs priorities identified by the network as a whole. This chapter begins with a brief discussion of the reasoning behind Vital Signs monitoring and the development of the Vital Signs framework. It then explains the process the network has used to prioritize the list of potential Vital Signs, both for each park and across the network. Lastly, it describes the process by which the PACN will select the set of Vital Signs for initial implementation.

B. BACKGROUND

The primary purpose of Vital Signs monitoring is to identify and keep track of "the most significant indicators of ecological condition and the greatest concerns of each park" so that park managers will have the broad-based, scientifically sound information they need to manage park resources and to work with the public and other agencies to sustain park resources. Park managers are directed by the NPS Organic Act to preserve "unimpaired for future generations" the water, air, and geological resources of the parks, as well as the parks' flora and fauna and the ecological, biological, and physical processes that created the parks and continue to act upon them.

Vital Signs monitoring is a partnership among parks, programs, and agencies to characterize and determine trends in the condition of parks and other protected areas to assess the efficacy of management practices and restoration efforts and to provide early warning of impending threats. As part of our strategy for monitoring implementation, the Inventory and Monitoring Program will look for cost-leveraging opportunities with other agencies, programs, and groups with similar data and management needs.

The PACN region has several features which make it unique within the National Park Services and present both challenges and opportunities for a long-term monitoring program. These features include processes which tightly link the atmosphere, land, and ocean, shared stressors and resource concerns such as invasive species and increasing demand for limited water resources, a wide variety of ecosystems (often spatially small), high levels of species endemism, specialization, and endangered status, and strong existing native cultural traditions.

Areas for monitoring identified as significant based upon legal mandate include water quality, air quality, and endangered species. Other significant resources include ecosystems or communities recognized for their regional or global distinctiveness or imperiled status, endemic groups of species, and geological features (Table 3.1). The Vital Signs the PACN has identified and prioritized are focused to help us better understand and manage these resources, as well as ecosystem drivers, stressors, and threats.

Table 3.1. Unique and threatened PACN ecosystems, communities, and groups.

Resource	Significance
Ecological Distinctiveness	
tropical alpine bogs & cloud forests	Tropical alpine bogs and cloud forests are rare throughout the Pacific Islands, and imperiled worldwide by human activity and climate change.
anchialine pools	Rare worldwide, they are only nationally represented in Hawaii, and are imperiled by development and invasive species.
tropical alpine deserts	Insular tropical alpine deserts are very rare, being found only on islands with very high elevations.
lakes and ponds	Kauhako Lake is geologically unique worldwide, having the largest depth: surface area ratio of any lake in the world.
offshore islets	A small number of islets offshore of the main Pacific islands provide predator-free refugia for native plants and animals.
Imperiled Ecosystems	
coastal wetlands (including mangrove wetlands)	Coastal wetlands, especially mangrove forests, are rare throughout the ecoregion and globally imperiled by development.
streams	Most streams on Pacific Islands are affected by water diversion, habitat alteration, and alien species invasions.
coral reefs	These highly productive habitats are globally imperiled by climate change and human activity.
seagrass meadows	Seagrass meadows are rare throughout the region. Globally imperiled by human activity and climate change.
tropical rainforest	Tropical rainforests worldwide have been heavily affected by logging and development.
tropical dry forests	Originally rich in endemic plants, this vegetation zone just above the coastal zone has been heavily affected by development.
Endemic Groups	
endemic plants	Multiple terrestrial, freshwater, and marine endemic species and species complexes are found within the PACN. Many of these species are endangered.
endemic invertebrates	Multiple terrestrial, freshwater, and marine endemic species and species complexes are found within the PACN. Many of these species are endangered.
endemic vertebrates	Multiple terrestrial, freshwater, and marine endemic species and species complexes are found within the PACN. Many of these species are endangered.
Geological Features	
volcanoes	Mauna Loa and Kilauea are two of the most active and well-studied volcanoes in the world.

C. Vital Sign Development, Prioritization, and Selection

5 The steps taken in development, prioritization, and selection of Vital Signs are illustrated in Figure 3.1. The first stage in Vital Sign development defined goals and objectives of the monitoring program, reviewed available information about park resources, ecosystems, stressors, and concerns, and identified key characteristics of ecosystem integrity. For more information about this process and its results, see Chapter One.

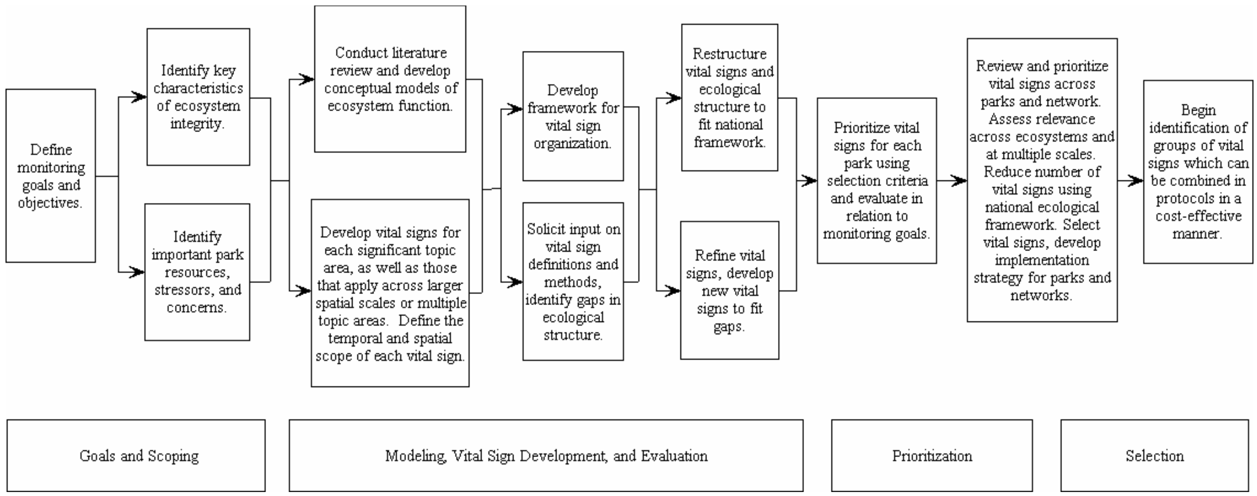

Figure 3.1. Chart of the steps taken in PACN Vital Signs selection.

1. Modeling, Vital Sign Development, and Evaluation

In the Vital Sign development stage, we conducted thorough literature reviews, constructed conceptual models of ecosystem function, and developed an initial list of Vital Signs for each topic area, as well as those that applied across broader scales. During this step, we also solicited advice from the scientific community concerning key ecosystem attributes within particular ecosystems or topic areas. For details about conceptual modeling, see Chapter Two.

The development stage also involved refining Vital Signs, restructuring our conceptual ecological framework to comply with the national framework, and creating new Vital Signs to fill gaps identified during this stage. The process of organizing Vital Signs and reviewing monitoring objectives identified areas of overlap, as well as gaps in the initial list of Vital Signs. Appropriate modifications, additions, and deletions were subsequently completed. Suggestions received at the Vital Signs Workshop in March 2004 also resulted in significant modifications and additions to the list of Vital Signs.

2. Prioritization of Vital Signs

The evaluation and prioritization stage required evaluating and prioritizing Vital Signs for implementation in each park. Potential Vital Signs were prioritized by staff at each park based upon four weighted criteria:

- Ecological significance (30% of total score)
- Management significance (30%)
- Legal mandate (20%)
- Cost-effectiveness (20%)

A database was developed to allow each park to independently rank each Vital Sign according to the criteria identified above. Guidance provided by PACN staff recommended that each park assemble a small team of resource managers to complete the Vital Sign ranking exercise, and that these teams seek input from outside experts as appropriate. The database allows parks to review detailed information about each Vital Sign, rank Vital Signs, view Vital Sign ranking summaries, and revisit the rankings as desired. While the database provides a standard mechanism for capturing park Vital Sign priorities, certain aspects of its use were more successful than others. The intended approach was for small group discussion when deciding on priorities. This was time consuming, and in some cases the task of ranking Vital Signs fell to a single person. Another scenario was the database getting passed from one person to the next, which detracted from the collaborative process and gave the greatest weight to ranking decisions made by the last person in the chain.

Other I&M networks have also used a database to complete Vital Sign ranking. The intent is to standardize the ranking criteria and to present each Vital Sign in a concise manner, maximizing the extent to which all persons involved view the Vital Signs in the same context and understanding. We found it necessary to refine Vital Signs based on feedback from the network parks, much of which was generated by the process of completing the ranking exercise. Therefore, completion of our ranking database process became iterative – we went through two significant Vital Sign refinements, and sent the database out three times. Although participants displayed some discrepancies in interpreting Vital Signs and some frustration about having to complete the ranking exercise more than once, we felt that the iterative ranking elicited constructive feedback, enhanced understanding of each Vital Sign, and resulted in a reasonably accurate prioritization of Vital Signs for our network.

Based upon feedback at the Vital Signs Workshop (March 2004), the prioritization criteria were simplified and refined and parks revised their priorities a third and final time. The final criteria are presented in Table 3.2. In an effort to reduce the total number of Vital Signs under consideration for funding, PACN staff revised the list of Vital Signs in a two-step process. The first step involved eliminating proposed Vital Signs that were duplicates or were more properly addressed as research questions, and streamlining certain substantially similar Vital Signs. A table of proposed Vital Signs removed from consideration during this process is available at http://www.nature.nps.gov/im/units/pacn/monitoring/plan/2004/index.htm, with short explanations of why each one was eliminated. The remaining full list of ranked Vital Signs is available at http://www.nature.nps.gov/im/units/pacn/monitoring/plan/2004/index.htm.

The second step in reducing of the number of proposed Vital Signs entailed creating a list of high-ranked Vital Signs for consideration. The criteria used for inclusion on the short list are:

- Each Vital Sign with a high network rank (less than 15) was included.
- Each Level Two category in the national framework (see Table 1.12) has at least one Vital Sign:
    - When there is only one Vital Sign in the Level Two category, it is included.
    - When there are several Vital Signs within the Level Two category, and all are low-ranked (below 50, and in approximately the bottom one-third of the list), then only the highest-ranked one is included.
    - When there are several Vital Signs within the Level Two category, and at least one is ranked greater than 50, then one-third of Vital Signs in that category are included.
- All Vital Signs listed within each park's numeric top five are included, regardless of network rank. The differing number of high-priority Vital Signs identified by each park generally reflects the diversity of resources and management concerns associated with the parks.

In addition to Vital Signs included on the short list using the above criteria, several Vital Signs were added to the list because they involved well-established monitoring programs monitoring air quality and volcanic activity. Table 3.3 shows the resulting draft short list of high-ranked PACN proposed Vital Signs.

Table 3.2. Vital Sign prioritization criteria.

Criteria (Weight)	Sub-Criteria	
Management Significance (30%)	**Very Low**: Data are of interest to the public, there is an application of the data to performance (GPRA) goals. **Low**: In addition to addressing a specific management decision, data provide information that strongly supports other management decisions. The Vital Sign address a wide-spread (pervasive) resource or issue. **Medium**: The Vital Sign will produce results that are clearly understood and accepted by park managers, other policy makers, research scientists, and the general public, all of whom should be able to recognize the implications of the Vital Sign's results for protecting and managing the park's natural resources. Data will permit managers to make informed decisions. **High**: There is an obvious, direct application of the data to a key management decision, or for evaluating the effectiveness of past management decisions. Monitoring results are likely to provide early warning of resource impairment, and will save park resources and money if a problem is discovered early.	
Ecological Significance (30%)	**Very Low**: Data from the Vital Sign are needed by the parks to fill gaps in current ecological knowledge. The Vital Sign complements Vital Signs at other scales and levels of biological organization. **Low**: The Vital Sign is sufficiently sensitive; small changes in the Vital Sign can be used to detect a significant change in the target resource or function. Reference conditions exist within the region, and/or threshold values are specified in the available literature that can be used to measure deviance from a desired condition. **Medium**: The Vital Sign represents a resource or function of high ecological importance based on the conceptual model of the system and the supporting ecological literature. The Vital Sign has a high signal to noise ratio and does not exhibit large, naturally occurring variability. **High**: There is a strong, defensible linkage between the Vital Sign and the ecological function or critical resource it is intended to represent. The Vital Sign provides early warning of undesirable changes to important resources and can signify an impending change in the ecological system.	
Legal/Policy Mandate (20%)	**Very Low**: There is no legal mandate for this particular resource/Vital Sign. **Low**: The resource/Vital Sign is listed as a sensitive resource or resource of concern by credible state, regional, or local conservation agencies or organizations, but it is not specifically identified in any federal or state legislation. The resource/Vital Sign is also covered by the Organic Act and other general legislative or Congressional mandates such as the Omnibus Park Management Act and GPRA. **Medium**: The resource/Vital Sign is specifically covered by an Executive Order (e.g., invasive plants, wetlands), a specific 'Memorandum of Understanding' signed by the NPS (e.g., bird monitoring), or specific Congressional mandates. The need to monitor the resource is generally indicated by some type of federal or state law or other general legislative mandates. **High**: The park is required to monitor this specific resource/Vital Sign by some specific, binding, legal mandate (e.g., Endangered Species Act for an endangered species, Clean Air Act for Class 1 airsheds), or park enabling legislation.	This criterion is part of 'Management Significance' but is purposely separated here to emphasize those Vital Signs and resources that are required to be monitored by some legal or policy mandate. The intent is to give additional priority to a Vital Sign if a park is directed to monitor specific resources because of some binding legal or Congressional mandate, such as specific legislation and executive orders, or park enabling legislation. The binding document may be with parties at the local, state, regional, or federal level.
Cost Effectiveness and Feasibility (20%)	**Very Low**: Cost effective management uses for data exist if data were available. **Low**: Partners exist for protocol development, data collection, or analysis. **Medium**: Protocol development is economically viable (or suitable protocols already exist). **High**: The Vital Sign has measurable results that are repeatable with different, qualified personnel. Actual monitoring (sampling and analysis) would be economically viable at an appropriate frequency and intensity.	

Table 3.3. Draft short list of high-ranked PACN proposed Vital Signs. (L=lowest third, M=medium third, H=highest third, NA=not applicable).

Level 1	Level 2	Vital Sign	Network Rank	AMME Rank	WAPA Rank	NPSA Rank	USAR Rank	KALA Rank	HALE Rank	ALKA Rank	PUHE Rank	KAHO Rank	PUHO Rank	HAVO Rank
Air and Climate	Air Quality	Visibility and particulate matter	39	L	M	L	M	M	H	M	M	M	M	H
	Weather and Climate	Weather/Climate[a]	8	H	H	H	H	H	H	H	H	H	M	H
Biological Integrity	At-risk Biota	Rare, threatened & endangered species	7	H	M	H	H	H	H	H	H	H	H	H
		Rare, threatened & endangered marine animals	13	M	M	H	H	H	M	M	M	H	H	H
		Rare, threatened & endangered terrestrial invertebrate populations	12	M	L	H	M	H	H	H	H	H	H	M
	Focal Species or Communities	Marine fish communities	24	M	H	H	H	H	L	M	M	H	H	L
		Focal freshwater animal species	31	M	L	M	NA	H	H	M	M	H	M	M
		Freshwater animal communities	19	H	H	M	NA	H	M	H	H	H	H	L
		Intertidal community	18	M	M	M	H	H	M	M	M	H	H	L
		Benthic marine invertebrate community	25	M	H	H	L	H	L	M	M	H	H	L
		Focal marine invertebrate species	14	M	H	H	H	H	M	M	M	H	H	L
		Focal terrestrial vertebrate species	50	H	L	M	L	M	H	M	NA	L	NA	M
		Forest birds and bats	32	H	NA	H	NA	H	H	L	L	L	H	H
		Focal terrestrial plant communities	9	H	H	H	L	H	H	M	M	H	H	H
		Focal terrestrial plant species	3	H	H	H	H	H	H	H	H	H	H	H
		Wetland and riparian plant communities	18	H	M	L	H	H	L	H	H	H	H	L
	Infestations and Diseases	Marine animal disease	35	L	M	H	M	M	L	M	M	H	H	L
	Invasive Species	Exotic invertebrates-status and trends	54	L	L	H	L	L	H	L	L	L	L	M
		Exotic terrestrial invertebrates-early detection	15	M	H	M	M	H	H	M	M	M	M	H

Level 1	Level 2	Vital Sign	Network Rank	AMME Rank	WAPA Rank	NPSA Rank	USAR Rank	KALA Rank	HALE Rank	ALKA Rank	PUHE Rank	KAHO Rank	PUHO Rank	HAVO Rank
		Exotic terrestrial vertebrates-early detection	11	M	H	M	H	H	H	M	M	H	M	H
		Exotic ungulates-status and trends	39	NA	H	H	NA	H	H	L	L	L	M	M
		Exotic aquatic plants-status and trends	21	H	H	L	H	M	M	H	H	H	M	L
		Exotic terrestrial plants- early detection	4	M	H	H	H	H	H	H	H	H	H	H
		Exotic terrestrial plants-status and trends	1	H	H	H	H	H	H	H	H	H	H	H
Ecosystem Pattern and Processes	Fire	Fire dynamics	47	NA	H	NA	NA	M	H	M	M	M	M	M
	Land Cover / Land Use	Land use patterns	5	M	M	H	H	H	H	H	H	H	H	H
		Wilderness use	65	NA	NA	NA	NA	NA	H	NA	NA	NA	NA	L
	Lightscape	Lightscapes	41	M	L	L	M	M	H	M	M	M	M	M
	Nutrient Dynamics	Nutrient cycling	37	M	M	M	M	M	M	M	M	M	M	M
	Soundscape	Soundscapes	39	L	L	L	M	M	M	M	M	H	M	M
Geology and Soils	Geomorphology	Shoreline change	26	M	L	L	H	H	H	H	H	H	H	L
		Dunes	66	NA	NA	NA	NA	NA	NA	NA	NA	NA	H	L
	Soil Quality	Erosion and deposition	29	M	H	L	M	M	H	M	M	M	H	L
	Subsurface Geologic Processes	Cave habitat	51	NA	H	L	NA	L	M	M	M	L	M	M
		Seismic activity[a]	56	L	L	L	L	M	M	L	L	L	L	L
		Mass wasting[a]	57	NA	L	M	NA	M	M	M	M	L	L	L
		Lava flows[a]	61	NA	NA	NA	NA	NA	M	M	M	L	L	M
Human Use	Consumptive use	Fisheries harvest	38	L	H	H	L	H	L	L	L	H	H	L
	Cultural Landscapes	Viewscapes	45	NA	NA	L	M	M	H	M	M	M	H	M

Level 1	Level 2	Vital Sign	Network Rank	AMME Rank	WAPA Rank	NPSA Rank	USAR Rank	KALA Rank	HALE Rank	ALKA Rank	PUHE Rank	KAHO Rank	PUHO Rank	HAVO Rank
	Point-Source Human Effects	Litter and debris	30	M	M	L	H	M	H	M	M	H	L	L
	Visitor and Recreation Use	Terrestrial visitor usage	16	H	L	L	H	H	H	H	H	H	H	L
Water	Hydrology	Wetland hydrology	31	H	L	L	NA	M	M	H	H	H	M	M
		Marine hydrography	23	M	M	H	H	H	M	M	M	M	H	L
	Water Quality	Toxics and contaminants	6	H	H	M	H	H	H	H	H	H	H	L
		Water quality core parameters	2	H	H	H	M	H	M	H	H	H	H	M
		Water quality supplemental parameters	10	H	H	H	H	H	M	H	H	H	H	L

a. These Vital Signs were included on the draft short list because they involve efforts by well-established programs monitoring air quality and volcanic activity.

3. Prioritized PACN Vital Sign Descriptions

The PACN Vital Sign selection committee will meet in early November 2004 to identify the set of Vital Signs to be initially funded for monitoring. Detailed Vital Sign justifications, monitoring questions, and proposed measures and metrics for consideration from the short list of Vital Signs (Table 3.3) to be used at this November 2004 funding and implementation meeting are available as Appendix G.

4. Vital Signs and Conceptual Models

This section presents the ecological context and rationale for consideration of the short list Vital Signs (Table 3.3). At an upcoming implementation meeting, we will be developing a final short list of Vital Signs for initial funding and implementation, as well as a “hold” list for future funding. These Vital Signs target the significant resources identified earlier in this chapter, either to improve our understanding and management of these resources themselves, or to address threats, stressors, and drivers that may affect them and also need management attention.

The following section uses the Jenny-Chapin model of ecosystem sustainability (see Chapter 2 for detail) as a framework for discussion. An illustration of the Jenny-Chapin model is repeated below (Fig. 3.2) for reference when comparing Vital Signs with conceptual models. In this model, the circle represents the bounds of the ecosystem. State factors (major forces of external influence on ecosystems) are depicted outside the circle, and interactive controls (which both influence and respond to ecosystem processes) are inside the circle. In this discussion, Vital Signs are ordered by the Inventory and Monitoring Program’s national Vital Signs organizational framework (as in Table 3.3).

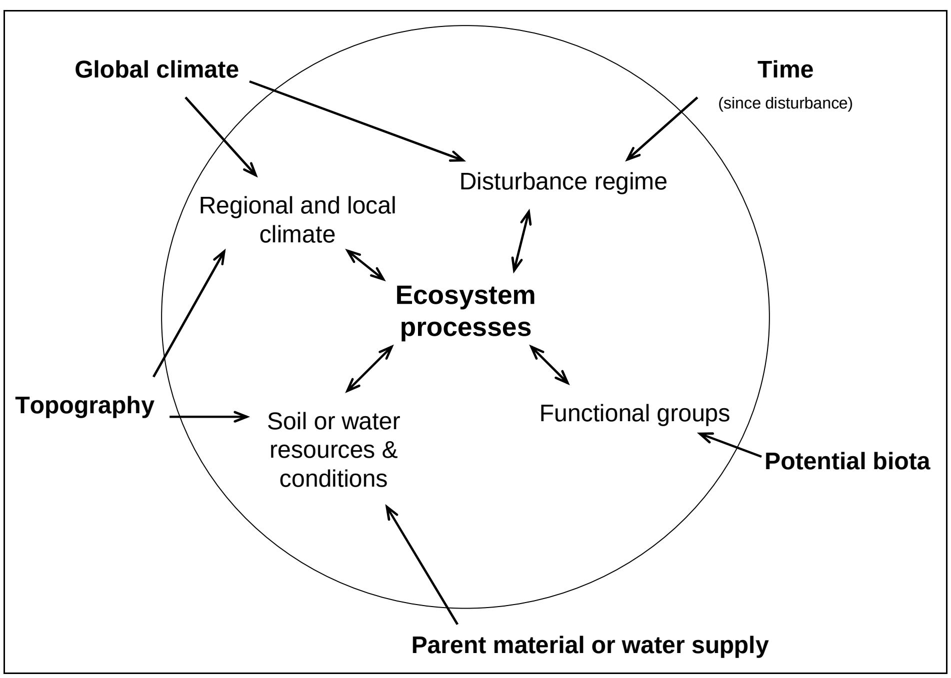

Figure 3.2. The Jenny-Chapin interactive-control model (modified from Evenden et al. 2002).

Air Quality and *Climate* are the two elements that compose the concept of “regional and local climate”, one of the four interactive controls of the Jenny-Chapin model of ecosystem sustainability (Figure 2.3).

- *Air quality*: Several measures of air quality were considered as potential PACN Vital Signs, including particulate and gaseous air contaminants, solar radiation inputs, visibility and particulate matter, and both wet and dry atmospheric deposition. The Vital Sign "Visibility and particulate matter" was ranked highest overall during the ranking process. Under the PSD (Prevention of Significant Deterioration) program, the NPS is required to monitor visibility and work to prevent any future, or remedy any existing, impairments of visibility in Class I areas. The PACN will evaluate the status of existing air quality, such as Air Contaminants and Solar Radiation monitoring that is ongoing at a single site, and extend such monitoring to the remaining Class I and Class II parks where feasible to broaden our spatial understanding of these resources.
- *Weather and climate*: incorporates aspects of the interactive control "disturbance regime". Several strategies for weather and climate monitoring were considered as potential PACN Vital Signs. Weather monitoring serves to: inform visitors of extreme weather conditions that may pose a health and safety risk, predict the likelihood of brush fires, provide baseline data to characterize ecosystems (as per NPS-I&M guidelines), provide supportive information to other studies (hydrology/ground water/stream flow, mass wasting, etc.), provide data for climate mapping, and provide indicators of changing climatic conditions. A long term meteorological monitoring program across the PACN region is essential to characterize the climate and to evaluate the influence of climate or climate change on ecosystems.

Biological Integrity is addressed in the Jenny-Chapin ecosystem sustainability model by the concept of "functional groups". The PACN has identified Vital Signs that also include species that do not play important functional roles in communities but that have other important values (e.g., endemic, invasive, endangered, and culturally important species).

- *At-risk biota*: The PACN parks contain a large number of at-risk species, both proportionally and overall for the nation as a whole, and they are an important aspect of biodiversity. Three high-ranked vital signs specifically address at-risk species: "Rare, threatened, and endangered species" (a Vital Sign which would track numbers of at-risk species in all functional groups), "Rare, threatened, and endangered marine animals", and "Rare, threatened, and endangered terrestrial invertebrate populations". Parks are mandated (e.g., Endangered Species Act, Marine Mammal Protection Act, NPS Management Policies) to monitor their condition and implement conservation activities to further their recovery. Rare invertebrates frequently exhibit characters that are unique for their group and thus evolutionarily significant on a global scale. Species of Concern and other rare species also form a major part of the natural resources parks are mandated to protect. Several of the vital signs included in the "Focal species and communities" category also involve at-risk species.
- *Focal species and communities* include marine fish communities, freshwater animal species and communities, intertidal communities, marine invertebrates (both benthic communities and focal species), terrestrial vertebrate species, forest birds and bats, terrestrial plant species and communities, and wetland and riparian plant communities as Vital Signs. The community-related Vital Signs are focused on communities or assemblages as indicators of overall dynamics, productivity, diversity, habitat quality, and habitat change. The species-related Vital Signs are focused on populations and individual species (particularly threatened and endangered species) as indicators of change, by

monitoring growth, distribution, reproduction, or recruitment, and early warnings. Combined, both focal species and communities provide information that addresses the "functional groups" interactive control of the Jenny-Chapin ecosystem sustainability model.

- *Infestations and diseases* can directly kill or weaken organisms and impair their ability to survive other stressors. Infestations and disease can also interfere with reproduction, growth, and other organismal functions. Marine animal disease (such as coral bleaching and fibropapilloma tumors) and terrestrial vertebrate disease (such as West Nile Virus) monitoring are examples of existing efforts to mitigate these impacts. It is necessary to broaden the scope of these efforts, as well as initiate monitoring efforts for other diseases, in order to adequately prevent the Jenny interactive control of "disturbance regimes" from being a significant factor as it relates to disease.
- *Invasive species*: Vital Signs pertaining to invasive species include both status and trends of established species and early detection of incipient species. Several groups of invasive species have been identified as being of concern: exotic terrestrial invertebrates, exotic terrestrial vertebrates (and, more specifically, exotic ungulates), exotic aquatic plants, and exotic terrestrial plants. Invasive species, which represent both "functional groups" and "disturbance regime" in the Jenny-Chapin ecosystem sustainability model interactive controls, have altered nearly all ecosystems in the PACN. Status and trend information is needed to help managers improve strategies for control, eradication, management of secondary effects, and native restoration, while early detection is needed to help limit the spread of incipient species and prevent the introduction of new species.

Ecosystem Pattern and Process is addressed in the Jenny-Chapin ecosystem sustainability model by the interactive controls: "disturbance regimes", "topography", "potential biota", "parent material or water supply", and "soil or water resources and conditions". The PACN has identified Vital Signs that encompass a range of disturbance factors, primarily driven by human activity, as well as natural patterns and processes.

- *Fire*: Ecosystems in the PACN are not adapted to fire, and fire is believed to have been quite rare in a natural context. Fire impacts ecosystems at all levels, from landscape to species, including: conversion of vegetation types, wildlife and food resources, nutrient cycles, water quantity and quality. Fire is addressed in the Jenny-Chapin ecosystem sustainability model by the interactive control "disturbance regime". In addition, a separate ecosystem process model linking fire with woody vegetation and grassland/savannahs is presented (D`Antonio and Vitousek 1992), with a feedback loop between fire and grassland/savannah systems that reinforces the presence of both components at the expense of woody vegetation.
- *Land cover/ land use*: in the PACN is an especially significant issue, as the islands that comprise the network inherently limit available space and raise awareness of this topic. Alterations in land use and cover may contribute to and be indicative of pollution of water and air resources, fragment habitat, alter movement patterns of wildlife, increase soil erosion, and facilitate the introduction of alien and invasive species. Additionally, designated wilderness necessitates more stringent land use management in order to preserve 'wilderness character' within and adjacent to designated areas. Land cover/land use affects most all aspects of the Jenny-Chapin ecosystem sustainability model, but

especially the interactive controls of "disturbance regime", "functional groups", and "soil or water resources and conditions".

- *Lightscape*: affects visitor experiences (seeing night skies and other resources in an unimpaired condition) as well as biological resources (birds being attracted to lights or turtle hatchlings not making it to the sea but instead moving toward the brighter inland horizon). Lightscapes are addressed in the Jenny-Chapin ecosystem sustainability model by the interactive control: "disturbance regime".
- *Nutrient cycling*: Patterns of nutrient cycling are essential ecosystem processes, and the links to decomposition and other processes and patterns are often complex yet critically important. They link biotic and abiotic components through a constant exchange of elements. As such, they may be considered an integrating variable, as they occur across scales and involve the atmosphere, biosphere, lithosphere, and hydrosphere. While long-range, even global, transport is often involved, the key transformations that make these elements available to plants (and so to animals) are driven by soil and sediment microbes (or marine benthic organisms), as are the reactions that release the elements back to air or water, to repeat the cycle. In most cases, well established ecosystems have very "tight" nutrient cycles that conserve key nutrients. Nutrient cycling is addressed in the Jenny-Chapin ecosystem sustainability model by the interactive control "soil or water resources and conditions", although it is also closely tied to every other state factor and interactive control.
- *Soundscape*: integrates natural conditions, indirect effects of land-use practices, and human noise. Natural quiet (the absence of anthropogenic sounds) and natural sound sources (wind, wave, water, or native biota) are key components of this identified Vital Sign. Noise introduced from non-native species, as well as the absence of natural sounds where human practices have altered ecosystem processes (such as the loss of the sound of rushing water after stream diversion, loss of wave noise with altered shoreline profiles, or loss of birdsong with species extinction) are also key constituents of this Vital Sign. Finally, human originated sounds, including aircraft, automobiles, motorboats, visitors, and activities external to the park are all anthropogenic sources affecting soundscape resources. Soundscapes are addressed in the Jenny-Chapin ecosystem sustainability model primarily by the interactive control of "disturbance regimes".

Geology and Soils encompasses the interactive controls "disturbance regime" and "soil or water resources and conditions" in the Jenny-Chapin model of ecosystem sustainability.

- *Geomorphology*: Shoreline morphology affects both coastal and marine resources, such as wetlands, tidepools, coral reefs, and seagrass beds. Dunes, both inland 'desert' and coastal windblown features and processes, are unique resources and provide habitat. Over time, this geomorphology is part and parcel of local topography and the condition of parent materials. Geomorphology is addressed in the Jenny-Chapin ecosystem sustainability model by the interactive control "soil or water resources and conditions" and "disturbance regime".
- *Soil quality*: Erosion and sedimentation are directly indicative of soil disturbance and provide a good indicator of the rate or extent of land use change. When suspended in water, fine sediments increase turbidity, decrease light penetration, alter primary productivity, and modify geomorphologic processes. In some cases excessive sedimentation or erosion can alter the hydrologic regime. Soil quality is addressed in the

Jenny-Chapin ecosystem sustainability model by the interactive controls “soil or water resources and conditions” and “disturbance regime”.

- *Subsurface geological processes*: Volcanic features (both surface and subsurface) and processes, mass wasting, as well as cave conditions are identified as PACN Vital Signs. Environmental conditions in caves and lava tubes are easily disturbed by human activity. However, caves and lava tubes are often important traditional cultural sites. Mass wasting modifies gross morphological characteristics through downslope movement of regolith, and is important to human safety, facilities, and understanding surface disturbances and the origins of soil conditions. The PACN also has the most active volcanic features and processes in the world in HAVO, while Guam & CNMI are currently monitored for their ongoing activity, while NPSA has a historic, albeit complex, record of volcanism. Lava flows affect both human safety, park facilities, and have wide ranging affects on ecosystem process beyond just modifying surface morphology. Volcanic deformation also impacts human safety and park facilities, as well as having often subtle but significant effects on natural processes such as modifying drainage patterns. Subsurface geological processes are addressed in the Jenny-Chapin ecosystem sustainability model by the interactive controls “disturbance regime” and “soil or water resources and conditions”.

Human Use. While not a part of the Jenny-Chapin ecosystem sustainability model, the PACN recognizes that human use of natural resources is an integral part of ecosystem function. Subsequent authors using this model (e.g. Vitousek, 1995) have in fact, included human activity in modified versions of this model.

- *Consumptive use*: Fisheries harvest is the Vital Sign associated with consumptive use that the network identified as highest priority. In the Pacific, a wide variety of marine species, both vertebrate and invertebrate, are fished for consumptive and commercial uses. Fishing has significant, well documented, impacts on ecosystem structure and function, and on the condition of resources. Fishing is increasingly documented as being the principal threat to Pacific coral reefs and other marine ecosystems worldwide. In this sense, it is addressed by the Jenny-Chapin ecosystem sustainability model interactive controls of “disturbance regime” and “functional groups”.
- *Cultural landscapes*: Viewscapes are identified as a Vital Sign by the network. They are particularly relevant in Class 1 (Clean Air Act designation) parks which have designated viewsheds that are not to be obstructed or impaired. Viewscapes also integrate many of the elements of the Jenny-Chapin ecosystem sustainability model into a descriptive summary of ecosystem pattern.
- *Point-source human effects*: As a Vital Sign, litter and debris can be physically harmful to animals and plants, particularly by entanglement or smothering. The presence of litter diminishes visitor experience and is regulated, in marine habitat, by the International Convention for the Prevention of Pollution from Ships (MARPOL; 1973, 1978 and other statutes). Point-source human effects are addressed in the Jenny-Chapin ecosystem sustainability model by the interactive control “disturbance regime”.
- *Visitor and recreation use*: The PACN has identified terrestrial visitor use as a high-priority Vital Sign. Human visitor impacts can affect habitat by influencing successional stages of vegetation, structural differentiation, nutrient cycles, forage availability, water quality and quantity yields, successional pathways, wildlife variety and quantity, carbon balances, and scenic variability. Human actions can significantly alter the extent,

intensity, duration and periodicity of disturbance events (e.g., permanent vehicle traffic routes, pesticide spraying, vegetation removal, etc.). Human actions can also lead to disturbance rates that surpass the ability of biological systems to respond to or recover from the resulting changes. Visitor use affects ecosystem patterns and processes at virtually all scales, and must be addressed accordingly. Visitor and recreation use is addressed in the Jenny-Chapin ecosystem sustainability model by the interactive control "disturbance regime".

Water is part of the concept of "soil or water resources and conditions", one of the four interactive controls of the Jenny-Chapin ecosystem sustainability model.

- *Hydrology*: Monitoring of hydrology is important in predicting changes in water resources and conditions. The PACN has identified two high-priority hydrology Vital Signs: wetland hydrology and marine hydrography. Monitoring of wetland hydrology is required for predicting the effects of natural and human-induced hydrological changes (e.g. sea level rise, drought conditions, groundwater withdrawal) and the fate of contaminants in the ecosystem. Marine hydrography monitoring is important in predicting the effects of storms and high wave events, as well as for monitoring more subtle changes in hydrology such as dominant wave and current patterns.
- *Water quality* is an important aspect of water resources and conditions. Water quality is further subdivided into water chemistry, toxics, and microorganisms. Water chemistry includes the core parameters (temperature, conductivity/salinity, dissolved oxygen, pH, total nitrogen, total phosphorous, photosynthetically active radiation, chlorophyll a, and depth) required to provide a minimum level of data for baseline water quality assessment. Supplemental parameters provide important information for further characterizing specific water resources, identifying potential stressors, and detecting changes early. Toxics and contaminants reaching water resources negatively affect aquatic biota, human health, and local economics. Biological condition and microbial content can indicate impacts to water resources due to human and animal wastes and storm water runoff from urbanized and agricultural landscapes.

Table 3.4. Water bodies identified for Vital Sign monitoring, their status, and principal resource concerns for monitoring.

Park	Water Bodies	Status	Resource Concern(s)
WAPA	Marine – nearshore coastal (Asan & Agat units)	Threatened	Bacteria levels in nearshore areas, sedimentation, turbidity, dissolved oxygen, unexploded ordinance
	Rivers	Threatened	Sediment, nutrients/bacteria, and contaminants from land use practices and development (residential and light industry)
	Wetland (upland & coastal)	Unique	Sediment, nutrients/bacteria, and contaminants from land use practices and development (residential and light industry)
AMME	Wetland	Unique, threatened	Leachates from past dumping; terrestrial, urban runoff, including nutrients
	Stream	Impaired	Terrestrial, urban runoff, including nutrients, sediment and RO brine
	Marine – marina & mudflats	Impaired, adjacent to park	Sedimentation, leachates from landfill
	Marine – nearshore coastal	Threatened, adjacent to park	Nutrient/bacteria levels in nearshore areas, sedimentation
NPSA	Streams (Tutuila, Olosega, & Ofu islands)	Pristine	Documenting natural conditions, sediment and runoff (nutrients/bacteria) from agricultural and

Park	Water Bodies	Status	Resource Concern(s)
			developed areas
	Marine – Nearshore coastal (Tutuila, Olosega, Ofu, & Tau islands)	Pristine	Bays, coves, and open water: documenting conditions, runoff and cesspool leaching near developed areas
USAR	Pearl Harbor's East Loch (especially surrounding ship)	Impaired	Nutrients, metals, and contaminants from military and civilian development
	Halawa Stream	Impaired, adjacent to park	Nutrients, metals, and contaminants from highly urbanized developed areas
KALA	Kahauko Crater Lake	Unique	Documenting natural conditions, potential for sedimentation
	Streams	Pristine	Stream diversion and potential nutrients/bacteria. Includes site(s) on the Nature Conservancy's national list of "Priority Aquatic Sites for Biodiversity Conservation".
	Marine – nearshore coastal	Pristine	Documenting conditions
HALE	Sub-alpine lakes	Unique	Documenting conditions
	Bogs	Unique	Documenting conditions
	Streams	Pristine	Stream diversion and potential nutrients/bacteria from various land use practices, also includes an entire watershed, an unusual occurrence in Hawaii. Includes sites eligible for designation as national Wild and Scenic Rivers and sites on the Nature Conservancy's national list of "Priority Aquatic Sites for Biodiversity Conservation"
	Marine – nearshore coastal	Pristine, adjacent to park	Documenting conditions, potential nutrients/bacteria from adjacent areas and groundwater
ALKA	Anchialine Pools	Threatened	Contaminants and nutrients from visitor use and groundwater
	Marine – nearshore coastal	Threatened	Sedimentation, turbidity, chlorophyll *a*, and potential nutrients/bacteria from visitor use, surface flow, and groundwater
	Wetlands	Threatened	Sedimentation and nutrients, from visitor use, surface flow, and groundwater
PUHE	Pelekane Bay	Impaired	Sedimentation, turbidity, chlorophyll *a*, and nutrients from upslope land use (primarily agriculture and harbor development)
	Makahuna Stream / Makeahua Gulch	Threatened	Sedimentation, turbidity, chlorophyll *a*, and nutrients from upslope land use (primarily agriculture and harbor development)
KAHO	Anchialine Pools	Threatened	Contaminants and nutrients in groundwater from adjacent land use
	Kaloko & `Aimakapa Ponds	Threatened	Contaminants and nutrients in groundwater from adjacent land use
	Marine – nearshore coastal	Threatened	Contaminants and nutrients from boat harbor, and sedimentation from pond restoration, erosion, and potential harbor expansion
	Groundwater (existing monitoring wells)	Threatened	Contaminants and nutrients in groundwater from adjacent land use
PUHO	Anchialine pools / fishponds	Threatened	Sediment, nutrients, and contaminants from upslope development (agriculture and residential) as well as high levels of visitation
	Ki`ilea Stream	Threatened	Sediment, nutrients, and contaminants from upslope development (agriculture and residential) as well as high levels of visitation
	Marine – nearshore coastal	Pristine but threatened, adjacent to park	Sediment, turbidity, nutrients, and contaminants from upslope development (agriculture and residential) as well as high levels of visitation
HAVO	Anchialine pool complexes	Pristine	Documenting conditions, volcanic stressors, potentially nutrients from visitors

Park	Water Bodies	Status	Resource Concern(s)
	Olaa bogs (wetlands)	Pristine	Documenting conditions
	Marine – nearshore coastal	Pristine, adjacent to park	Documenting conditions, volcanic stressors

D. CONCLUSION

Identification and selection of PACN Vital Signs has been a dynamic process. The primary purpose of selecting Vital Signs is to identify and track indicators of ecological conditions and systems, and significant resources for individual parks and for the network as a whole. This broad-based, scientifically sound information allows better management of park resources. Selections must meet natural resource data needs, while remaining within budget and logistical limitations. Monitoring can be aided through partnerships among parks, programs, and other agencies.

The process of Vital Sign development included literature reviews, development of conceptual models of ecosystem function, gathering advice from the scientific community, and restructuring conceptual ecological framework to comply with the national framework. Potential Vital Signs were prioritized by staff at each park, and these rankings were used to create a short list of high-ranked Vital Signs. In November 2004, the PACN Vital Sign selection committee will use this list to identify the set of Vital Signs to be initially funded for monitoring, as well as a hold list for future funding. The PACN has identified and prioritized Vital Signs that are focused to help to better understand and manage natural and cultural resources and their threats, as well as ecosystem drivers and stressors.

CHAPTER 4. SAMPLING DESIGN

Will be prepared in 2005

CHAPTER 5. SAMPLING PROTOCOLS

Will be prepared in 2005

CHAPTER 6. DATA MANAGEMENT

Will be prepared in 2005

CHAPTER 7. DATA ANALYSIS AND REPORTING

Will be prepared in 2005

CHAPTER 8. ADMINISTRATION/IMPLEMENTATION OF THE MONITORING PROGRAM

Will be prepared in 2005

CHAPTER 9. SCHEDULE

Will be prepared in 2005

CHAPTER 10. BUDGET

Will be prepared in 2005

CHAPTER 11. LITERATURE CITED

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GLOSSARY

Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form employs management programs that are designed to experimentally compare selected policies or practices, by implementing management actions explicitly designed to generate information useful for evaluating alternative hypotheses about the system being managed.

Ahupua`a: Traditional system of land division in the Hawaiian Islands.

Amphidromy: Type of life history shared by most native Pacific Island stream organisms, in which species migrate between fresh and salt water at two points in their life cycle: from fresh to salt as embryos and from salt to fresh as juveniles (Fitzsimons et al. 2002).

Anchialine: Anchialine ponds or pools are brackish land-locked bodies of water with underground connections to the ocean. Their salinity varies in a delayed manner with the tides.

(Ecological) Attributes are any feature or process of the environment that can be measured or estimated and that may provide insight into the state of the ecosystem. Attributes are selected to represent the overall health of the system, known or hypothesized effects of stressors, or elements that have important human values. Examples include: diversity of native species, presence of alien species, and sediment in the water column. In PACN models, they are represented by an octagon.

Composition is defined as the identity and variety of elements within an ecosystem, including species present and their population structure, abundance, and genetic diversity (Noss 1990).

(Ecosystem) Drivers are major external forces of change to ecosystems, both natural and anthropogenic, including state factors. Examples of drivers include storm frequency and sea level rise, fire cycles, climate, and hydrological cycles. In PACN models, they are represented by a rectangle.

Ecological effects are the physical, chemical, biological, or functional responses of ecosystem components to stressors. In ecosystem conceptual models, they are also the working hypotheses of the links between environmental stressors and ecological attributes. Ecosystem effects are represented by a diamond in PACN models.

Ecosystem integrity implies the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes.

Focal resources are park resources that, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they would be monitored as an indication of ecosystem integrity. Focal resources might include ecological processes such as deposition rates of nitrates and sulfates in certain parks, or communities that play a disproportionately important role in the transfer of matter or energy or in the maintenance of landscape-level biodiversity.

Focal species include those species that play significant functional roles in the maintenance of ecosystem structure, function and composition (encompassing the concepts of keystone species, umbrella species, and ecosystem engineers) *as well as* those species that do not necessarily play significant functional roles but may be harvested, endemic, alien, or have protected status.

Function refers to how ecosystem parts interact with each other. Ecosystem functions include flow of nutrients or energy between ecosystem components and succession of biological communities after disturbance.

Heiau: In Hawaiian, a place of worship, including temples and shrines.

High island: An oceanic island with an elevation greater than 10 meters above high tide.

Hurricane: see **tropical cyclone**.

Indicators are a subset of monitoring attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2002). They are a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the system.

Interactive controls as defined in the interactive-control ecosystem sustainability model are drivers that generally operate inside the bounds of ecosystems. They respond dynamically to each other and interact with ecosystem processes, but are constrained by state factors (Chapin et al. 1996). They include: disturbance regime, biological functional groups, soil or water resources and conditions, and regional and local climate.

Matai: Traditional system of land management in the Samoan Islands.

Mauna: In Hawaiian, ‘mountain’.

(Ecological) Measures are the specific variables used to quantify the condition or state of an attribute (or Vital Sign). These are specified in definitive sampling protocols. One example is stream flow as an attribute, while discharge measurements in cubic feet per second are the measure. In PACN models, they are represented by a parallelogram.

State factors as defined in the interactive-control ecosystem sustainability model are variables with independent variation which function as ultimate controls on ecosystem structure and function (Chapin et al. 1996). They are considered ecosystem drivers. They are major forces of change in ecosystems, and may be affected by human activity. State factors include: time since disturbance, potential biota, parent material or water supply, topography, and global climate.

(Environmental) Stressors are physical, chemical, or biological perturbations to a system that may be either foreign or natural to the system, but applied at an excessive or deficient level (Barrett et al. 1976). Stressors often move the ecosystem away from desired future conditions through forcing change in ecosystem composition, function, or structure. Examples include: air pollution, water pollution, water withdrawal, pesticide use, land-use change, and introduction of invasive terrestrial, marine, and aquatic species. Stressors act together with drivers to influence ecosystem attributes. In PACN models, they are represented by an oval.

Structure is the physical organization or spatial patterns of organisms and habitats (i.e., the arrangement of species in space). Structure can be seen at widely divergent spatial scales, from the micro-scale structure in a patch of moss growing on a stream boulder to the landscape-scale three-dimensional profile of a coral reef system as measured from sandy shore to outer reef.

Tropical cyclone: For simplicity, we use the term topical cyclone in this report for the entire PACN region to refer to storms with sustained wind speeds above 63 knots/hr even though the terminology varies by geographic region.

Typhoon: see **tropical cyclone**.

Vital Signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital Signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes). Because of the need to maximize the use and relevance of monitoring results for making management decisions, Vital Signs selected by parks may include elements that were selected because they have important human values (e.g., harvested or charismatic species) or because of some known or hypothesized threat or stressor/response relationship with a particular park resource.